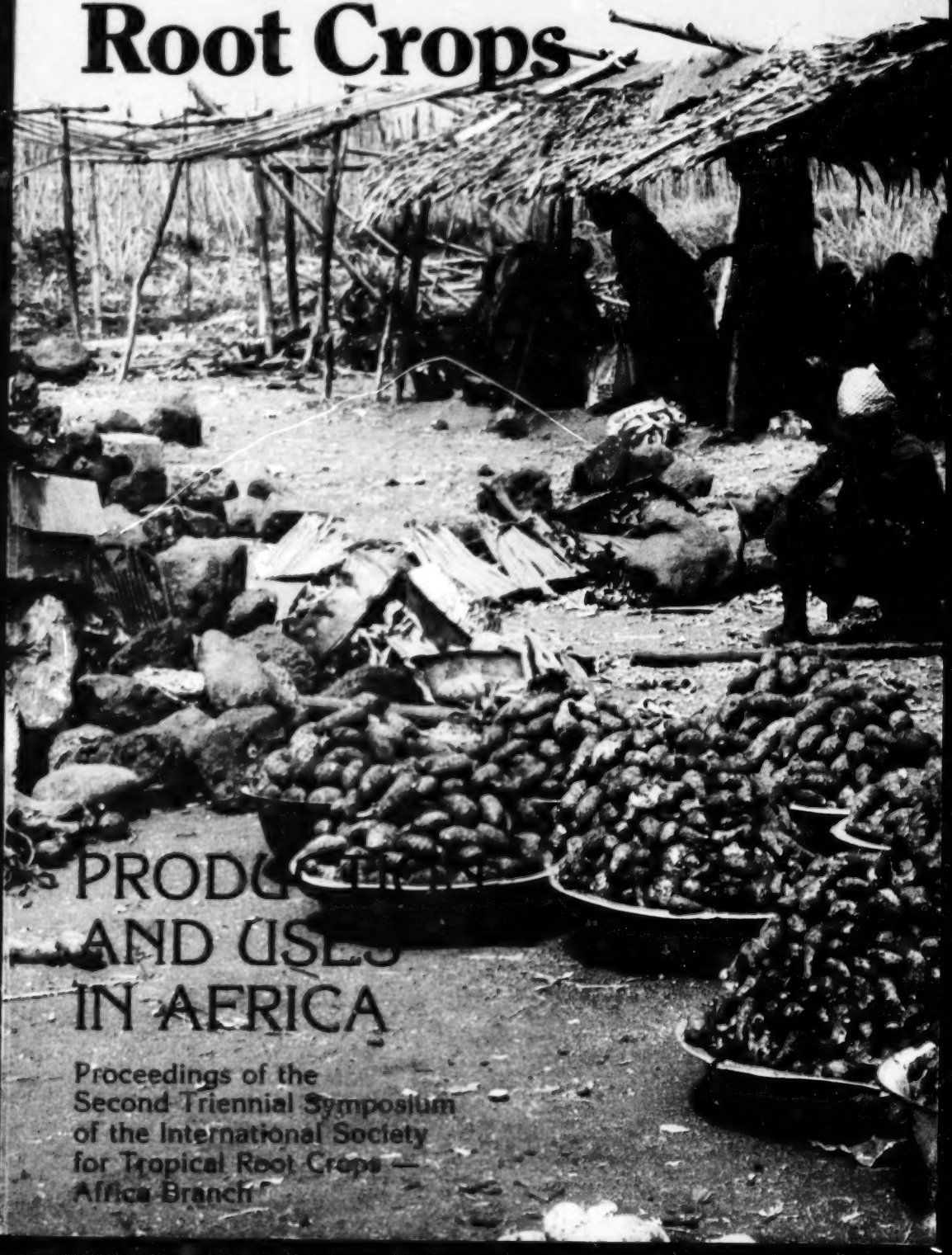
Tropical Root Crops



PRODUCTION AND USES IN AFRICA

Proceedings of the
Second Triennial Symposium
of the International Society
for Tropical Root Crops —
Africa Branch

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The International Society for Tropical Root Crops — Africa Branch was created in 1978 to stimulate research, production, and utilization of root and tuber crops in Africa and the adjacent islands. The activities include encouragement of training and extension, organization of workshops and symposia, exchange of genetic materials, and facilitation of contacts between personnel working with root and tuber crops. The Society's headquarters are at the International Institute of Tropical Agriculture in Ibadan, Nigeria, but its executive council comprises eminent root and tuber researchers from national programs throughout the continent.

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Postal Address: Box 8500, Ottawa, Canada K1G 3H9
Head Office: 60 Queen Street, Ottawa, Canada

Terry, E.R.
Doku, E.V.
Arene, O.B.
Mahungu, N.M.

International Society for Tropical Root Crops. Africa Branch, Ibadan NG

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TROPICAL ROOT CROPS: PRODUCTION AND USES IN AFRICA

Abstract

A mixture of original research, updates on procedures, literature reviews, and survey reports, this document resulted from the second symposium of the International Society for Tropical Root Crops — Africa Branch, with 77 participants from 16 countries. The focus was cassava, yams, cocoyams, and sweet potatoes, from the perspectives of breeders, agronomists, soil specialists, plant pathologists, entomologists, nutritionists, food technologists, etc. Learning from past successes and failures, many of the researchers directed their efforts toward problems obstructing progress in reaching improved production and use of root crops and attempted to view, realistically, the context in which their results would be applied.

Résumé

Résultats de recherches récentes, mises à jour sur les méthodes de recherche, revues de publications et rapports de sondages sont contenus dans ce document issu du Deuxième symposium de la Société internationale pour les plantes-racines tropicales — Direction Afrique, qui a réuni 77 participants de 16 pays. Des communications sur le manioc, le taro, le yam et la patate douce ont été présentées par des phytosélectionneurs, des agronomes, des pédologues, des phytopathologistes, des entomologistes et des spécialistes de la nutrifion et des aliments, entre autres. Tirant leçon de leurs succès et de leurs échecs, beaucoup de ces chercheurs ont dirigé leurs efforts vers la solution des problèmes qui entravent l'augmentation de la production et de la consommation des plantes-racines et ont tenté de considérer d'un œil réaliste le contexte qui sera celui de l'application de leurs recherches.

Resumen

Una mezcla de investigaciones originales, actualizaciones de procedimientos, reseñas de literatura e informes de encuestas, este documento es el resultado del segundo simposio de la Sociedad Internacional de Raíces Tropicales, Filial Africana, que contó con 77 participantes de 16 países. El simposio se centró en la yuca, el ñame, el cocoñame y las batatas, desde la perspectiva de los fitomejoradores, los agrónomos, los especialistas en suelos, los patólogos vegetales, los entomólogos, los nutricionistas, los tecnólogos alimenticios, etc. A partir de los éxitos y fracasos anteriores, muchos de los investigadores encaminaron sus esfuerzos hacia los problemas que obstaculizan el avance para lograr una producción y un uso mejorados de las raíces y trataron de obtener una visión realista del contexto en que los resultados pueden ser aplicados.

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TROPICAL ROOT CROPS:
PRODUCTION AND USES IN AFRICA

EDITORS: E.R. TERRY, E.V. DOKU, O.B. ARENE, AND N.M. MAHUNGU

PROCEEDINGS OF THE SECOND TRIENNIAL SYMPOSIUM OF THE INTERNATIONAL SOCIETY FOR TROPICAL ROOT CROPS — AFRICA BRANCH HELD IN DOUALA, CAMEROON, 14 – 19 AUGUST 1983

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FOREWORD

Exchange of information among researchers, which is a key to progress, is seriously constrained in Africa, because of the paucity of scientific journals published by and for the continent as well as the unreliable communications between countries. Scientific meetings, such as the triennial symposium of the International Society for Tropical Root Crops — Africa Branch, provide a much-needed forum for sharing results and redirecting and intensifying research efforts.

This volume is the result of the second symposium, which brought together 77 participants from 16 countries and was held in Douala, Cameroon, 14–19 August 1983.

A majority of the 56 scientific papers report research on cassava, which is by far the most important root crop in Africa. Contributions range from a method of quantifying the potential for progress in genetic improvement of cultivars to a procedure for quickly processing and enriching a popular traditional food — *fufu*.

The papers about yams are equally diverse, ranging from identification of natural antifungal compounds within the yam peel to the processing and consumer testing of flour from *Dioscorea dumetorum*.

Although substantially fewer, the papers on cocoyams and sweet potatoes also cover a wide range of subjects such as in-vitro methods for cocoyam improvement and on-farm trials as a means to test and transfer techniques in sweet-potato production.

All the papers published in this volume were selected for their contribution toward the achievement of production and utilization potentials of root and tuber crops in tropical Africa, which was the theme of the symposium. For instance, information is provided that will be useful to breeders who need to know what varietal characters to select for and to entrepreneurs interested in setting up processing plants.

The research priorities, identified at the first triennial symposium, remain valid, with diseases and pests still high on the list of major factors limiting root-crop production on the continent. Planting material is still in short supply, although tissue culture and other techniques provide promising avenues for rapid multiplication, wide distribution, and long-term germ-plasm conservation. Also critical is a shortage of trained personnel and funds, a perennial problem worldwide but especially daunting during the current economic squeeze.

The present economic problems facing many African countries make the financial support from the government of Cameroon, for the major portion of the symposium, all the more significant. Alone, the Cameroon government

sponsored 19 non-Cameroonian and 27 Cameroonian participants, as well as providing the venue, simultaneous French–English interpretation, and several symposium-related social events.

Support for the symposium and for this publication was also provided by the International Development Research Centre (Ottawa, Canada), the International Foundation for Science (Stockholm, Sweden), the National Root Crops Research Institute (Umudike, Nigeria), and the International Institute of Tropical Agriculture (Ibadan, Nigeria).

Eugene R. Terry
Editor-in-Chief
ISTRC — AB

PARTICIPANTS

A-As-Saqui, M. Central Agricultural Research Institute, P.O. Box 3929, Monrovia, Liberia

Acheampong, E. Department of Botany, University of Ghana, Legon, Accra, Ghana

Agboola, A.A. Agronomy Department, University of Ibadan, Ibadan, Nigeria

Agbor Egbe, T. Institut de recherches medicales et plantes medicinales, B.P. 6163, Yaounde, Cameroon

Agueguia, A. Institut de recherche agronomique, B.P. 13, Njombe, Cameroon

Akoroda, M.O. c/o Agronomy Department, University of Ibadan, Ibadan, Nigeria

Alvarez, M. International Institute of Tropical Agriculture, P.M.B. 5320, Ibadan, Nigeria

Ambe, T.J. Institute of Agronomic Research, P.M.B. 25, Buea, Cameroon

Arene, O.B. National Root Crops Research Institute, P.M.B. 1006, Umudike, Umuahia, Nigeria

Atu, U.G. National Root Crops Research Institute, P.M.B. 1006, Umudike, Umuahia, Nigeria

Ayuk-Takem, J.A. Institute of Agronomic Research, Bambui, P.O. Box 80, Bamenda, Cameroon

Bakare, B. International Institute of Tropical Agriculture, P.M.B. 5320, Ibadan, Nigeria

Bell, A. Centre for Nutrition, General Delegation for Scientific and Technical Research, B.P. 6163, Yaounde, Cameroon

Bell, R. National Science Foundation, 1800 G Street, NW, Washington, D.C. 20550, USA

Chouinard, A. Communications Division, International Development Research Centre, P.O. Box 8500, Ottawa, Canada K1G 3H9

Coursey, D.G. Head, Plant Food Commodities, Tropical Development and Research Institute, 56/62 Gray's Inn Road, London, WCIX 8LU, England

Dahniya, M.T. Agronomy Department, Njala University College, University of Sierra Leone, Private Mail Box, Freetown, Sierra Leone

De Lafforest, J. Transla Ltd, 29 Villiers Street, London, WC2, England

Doku, E.V. Faculty of Agriculture, University of Ghana, Legon, Accra, Ghana

Eckebil, J.P. Institute of Agronomic Research, B.P. 2123, Yaounde, Cameroon

Ene, L.S.O. National Root Crops Research Institute, P.M.B. 1006, Umudike, Umuahia, Nigeria

Foyet, M. Institute of Agronomic Research. B.P. 13. Njombe. Cameroon

Gbedolo, Y.M. Unité de recherche et de production, Station d'Ina, B.P. 3, N'Dali, Benin

Gobina, S.M. Institute of Agronomic Research. P.M.B. 25. Buea. Cameroon

Gwangwa'a, T.S. Centre for Nutrition. General Delegation for Scientific and Technical Research. B.P. 6163. Yaounde. Cameroon

Hahn, S.K. International Institute of Tropical Agriculture. P.M.B. 5320. Ibadan. Nigeria

Hrishi, N.P. Mount Makulu Central Research Station. B.P. 7. Chilanga. Lusaka. Zambia

Igbokwe, M.C. National Root Crops Research Institute. P.M.B. 1006. Umudike. Umuahia. Nigeria

Ikeorgu, J.E.G. National Root Crops Research Institute. P.M.B. 1006. Umudike. Umuahia. Nigeria

Kamga Fondjo, F. Institute of Agronomic Research. B.P. 243. Douala. Cameroon

Karikari, S.K. Department of Agronomy. Ahmadu Bello University. P.M.B. 1044. Zaria. Nigeria

Kasele, I.N. Programme national manioc (PRONAM). B.P. 11635. Kinshasa. Zaire

Kilumba, N. Programme national manioc (PRONAM). Gandajika. B.P. 22. Mbuji-Mayi. Zaire

Kingue, E.L. Directeur general associaté camerounaise. Yaounde. Cameroon

Koloko, C. Provincial Delegation for Agriculture. Littoral Province. B.P. 257. Douala. Cameroon

Lema, K. International Institute of Tropical Agriculture. P.M.B. 5320. Ibadan. Nigeria

Leumassi, P. B.P. 1682. Yaounde. Cameroon

Lockard, R.G. Agency for International Development. P.O. Box 1445. Monrovia. Liberia

Lutaladio, N.B. Programme national manioc (PRONAM). B.P. 11635. Kinshasa. Zaire

Lyonga, S.N. Institute of Agronomic Research. Ekona Centre. P.M.B. 25. Buea. Cameroon

Mahungu, N.M. Programme national manioc (PRONAM). B.P. 11635. Kinshasa. Zaire

Maimo, A.M. Institute of Agronomic Research. B.P. 2123. Yaounde. Cameroon

Makambila, C. Université Marien Ngouabi. B.P. 69. Brazzaville. Congo

Makame, M. P.O. Box 159. Kizimbani. Zanzibar. Tanzania

Martin, G. Centre for Nutrition. General Delegation for Scientific and Technical Research. P.O. Box 6163. Yaounde. Cameroon

Massala, R. Département de biologie cellulaire et moléculaire. Faculté des sciences. Université Marien Ngouabi. B.P. 69. Brazzaville. Congo

Mbome Lape, I. Centre for Nutrition. General Delegation for Scientific and Technical Research. B.P. 6163. Yaounde. Cameroon

Morris, S.Z. Central Agricultural Research Institute. Box 3929. Suakoko. Liberia

Muimba-Kankolongo A. Programme national manioc (PRONAM). B.P. 11635. Kinshasa. Zaire

Mulindangabo, J. Institut des sciences agronomiques du Rwanda — Karama. B.P. 121. Kigali. Rwanda

Ndamage, G. Institut des sciences agronomiques du Rwanda — Rubona, B.P. 138, Butare, Rwanda

Neba, A. B.P. 161, Buea, Cameroon

Ngeve, J.M. Institute of Agronomic Research, B.P. 2067, Yaounde, Cameroon

Ngoka, D.A. National Root Crops Research Institute, P.M.B. 1006, Umudike, Umuahia, Nigeria

Ntanda, D. B.P. 5473, Douala, Cameroon

Numfor, F.A. Institute of Agronomic Research, B.P. 13, Njombe, Cameroon

Nwankiti, A.O. National Root Crops Research Institute, P.M.B. 1006, Umudike, Umuahia, Nigeria

Nwinyi, S.C.O. National Root Crops Research Institute, P.M.B. 1006, Umudike, Umuahia, Nigeria

Nya Ngatchou, J. General Delegation for Scientific and Technical Research, B.P. 1457, Yaounde, Cameroon

Nzietchueng, S. Institute of Agronomic Research, B.P. 44, Dschang, Cameroon

Oduro, K.A. University of Science and Technology, P.M.B. 5080, Port Harcourt, Nigeria

Ogundana, S.K. Department of Microbiology, University of Ife, Ile-Ife, Nigeria

Okezie, C.E.A. Department of Botany, University of Nigeria, Nsukka, Nigeria

Okigbo, B.N. International Institute of Tropical Agriculture, P.M.B. 5320, Ibadan, Nigeria

Otim-Nape, G.W. Serere Agricultural Research Station, P.O. Soroti, Uganda

Pfeiffer, J.H. Institute of Agronomic Research, B.P. 2067, Yaounde, Cameroon

Praquin, J.Y. Institute of Agronomic Research, B.P. 2123, Yaounde, Cameroon

Safo-Kantanka, O. Crop Science Department, University of Science and Technology, Kumasi, Ghana

Sauti, R.F.N. Makoka Research Station, Ministry of Agriculture, Private Bag 3, Thondwe, Malawi

Tata, F.T. Provincial Delegate for Agriculture, Box 491, Bamenda, Cameroon

Teri, J.M. University of Dar es Salaam, Chuo kikuu, Morogoro, Tanzania

Terry, E.R. International Institute of Tropical Agriculture, P.M.B. 5320, Ibadan, Nigeria

Unamma, R.P.A. National Root Crops Research Institute, P.M.B. 1006, Umudike, Umuahia, Nigeria

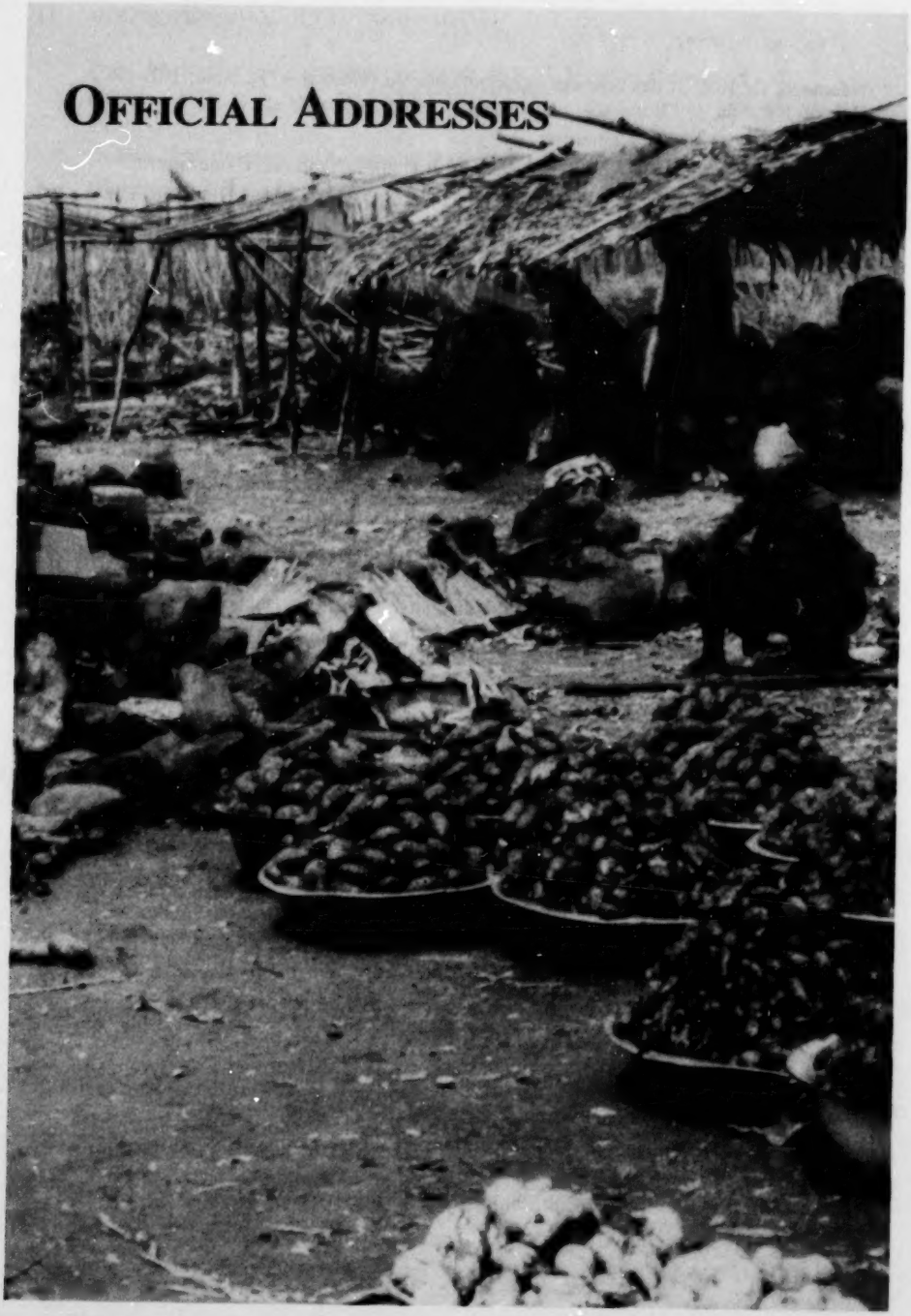
Vine, P.N. Department of Agronomy, University of Ibadan, Ibadan, Nigeria

Whyte, J.B.A. Institute of Agronomic Research, B.P. 13, Njombe, Cameroon

Wilson, M. Communications Division, International Development Research Centre, P.O. Box 8500, Ottawa, Canada K1G 3H9

Wonnuah, D.D. Central Agricultural Research Institute, Box 3929, Suakoko, Liberia

OFFICIAL ADDRESSES



Opening address

Nkaifon Perfura, Governor of the Littoral Province, Cameroon

I have the singular pleasure and pride in addressing, on behalf of the Government of Cameroon, this eminent assembly of scientists from all over Africa and beyond on the matter of the production and utilization of tropical root and tuber crops, which are staples for millions of people and animals in the tropical world. More than 300 million people of the humid and subhumid tropics depend on roots and tubers — one reason that the Government of Cameroon willingly and respectfully agreed to host this important symposium.

Permit me to stress the importance of this group of crops by reiterating certain facts and figures with which many of you are already familiar. The total world production of root and tuber crops excluding *Solanum* potatoes, in 1974, was 1.3×10^8 t, rising an average 2% yearly to 1.5×10^8 t by 1980–81. In 1980, world production of yams was 2.3×10^7 t, with Africa producing 98%; for cassava, the figures were 1.1×10^8 t and 42%; for cocoyams (macabo and taro), 4.3×10^6 t and 80%. In the total world production of sweet potatoes (1.5×10^7 t), Africa is second to Asia.

Production of root and tuber crops in Cameroon follows the same pattern as that for world production. The root crops contribute substantially to the diets of Cameroonians and receive considerable research attention. All scientific research matters in this country are placed under the control of the General Delegation for Scientific and Technical Research (DGRST), attached to the Office of the Prime Minister and directed by a Delegate General. Within DGRST, are five research institutes: the Institute of Agricultural Research, Institute of Zootechnical Research, Institute of Medical Research and Studies on Medicinal Plants, Institute of Mining and Geological Research, and the Institute of Social Sciences Research. These are the centres supported by local stations, substations, and research plots and fields.

This symposium is being held under the auspices of the Institute of Agricultural Research, which undertakes work in agriculture and forestry (excluding animals). Within this institute, there are 19 programs of research, and the root-crops program — the Cameroon National Root Crops Improvement Program (CNRCIP) — has, since 1978, been receiving financial assistance from the International Development Research Centre (IDRC, Canada), the General Administration on Cooperation in Development (AGCD, Belgium), the International Foundation for Science (IFS, Sweden), and technical and training assistance from the International Institute of Tropical Agriculture (IITA, Nigeria). The national government seizes this opportunity to thank the donors for their excellent gestures in international collaboration and for their support of this symposium.

The young International Society for Tropical Root Crops — Africa Branch is a part of the worldwide society that is concerned with eliminating constraints to production, quality, preservation, and utilization of tropical root and tuber crops. On behalf of the government, I thank Bede Okigbo, president of the Africa Branch, his executive, and the other members for choosing Cameroon as the venue for this second triennial symposium. It is an honour.

I will not list all the problems that researchers must work together to solve because the list is long and encompasses not only production but also harvesting, storage, and utilization. I know you, as researchers, will intensely focus your minds on these and other problems for the next 6 days in Douala, and I hope by interchange of ideas you will come up with recommendations that will guide governments in Africa to solve some of the problems.

I will not take more of your valuable time because you have a lot of work ahead of you.

I now have the pleasure of declaring open this symposium. Long live international cooperation; long live the United Republic of Cameroon.

PRESIDENTIAL ADDRESS

BEDE N. OKIGBO, INTERNATIONAL SOCIETY FOR TROPICAL ROOT CROPS — AFRICA BRANCH

I would like to begin by joining our hosts in welcoming you to this symposium. I would also like to remind you that we are gathered here today at a 3-year constitutional ritual. Here, we recount what has been — and is being — done throughout the world, but more especially in Africa, in realizing the objectives of this society. We discuss what has been accomplished in research, development, and utilization of roots and tubers and review new problems and ideas.

The aim of the ISTRC — AB in the tradition of the parent body is the promotion of increased production, research, improvement, processing, and utilization of tropical root and tuber crops — the crops with edible underground storage organs, such as cassava, yams, sweet potatoes, *Solanum* potatoes, and aroids, as well as minor crops in this group.

Our society was founded because these crops have not been given the attention and priority they deserve in research and development activities and because their yields and production in Africa are declining on a per-person basis, i.e., production has not kept up with the high rates of population growth. The latest figures from the Food and Agriculture Organization of the United Nations indicate that, in 1981, Africa accounted for 1.27×10^8 ha and 8.5×10^7 t of the world's root and tuber crops. These figures amounted to 26% of the world's total area and 15% of the world's total production. The world's average yield for root and tuber crops in 1981 was 6.7 t/ha, with a range in Africa from 1.3 t/ha for Mauritania to 18.5 t/ha for Egypt, followed by 16 t/ha for Reunión. At the same time, the lowest root and tuber yield outside Africa was 2.5 t/ha and the highest, 42.6 t/ha. Root and tuber crops in Africa and elsewhere in the developing countries continue to receive nutritional ratings and priority in research lower than those given to cereals because of the so-called low nutritional value of root crops. In this age of specialization, people reward athletes for their best performance in their chosen area. They are not rated on the basis of their weakest athletic activity. But root crops are not valued for their high efficiency in converting solar energy to calories and their high productivity. They are denigrated because they contain little protein. Yet, what humans require most in their diet is not protein or vitamins but carbohydrates, in which root crops are rich.

At the inaugural symposium 3 years ago, all members of the society noted with concern and dismay the relatively low support and priority given to roots and tubers compared with cereals. The allocation of resources and funds even by African countries where root crops are of major importance is meagre.

Although this is not the place to present a progress report on activities during the past 3 years, this address would be incomplete without some reference to developments worthy of note. At Centro Internacional de la Papa in Lima, Peru, this year, the International Society for Tropical Root Crops held its triennial symposium, and I hope that we who attended can share the information from that meeting with others during the short period that we are here together. The membership of the Africa Branch has continued to increase, but poor communications have made it difficult to keep up to date with activities outside one's own centre. The members of the executive have been in constant communication with each other but have failed to hold well-attended meetings mainly because of the lack of funds, continuing political and economic instabilities that bedevil many African countries, and logistic problems.

On behalf of the Africa Branch of the International Society, I hereby express appreciation to Dr Simon Lyonga and members of the local organizing committee. The generosity of the Cameroon government in sponsoring this symposium and an earlier seminar on yams is acknowledged. Thanks also go to other donors.

Closing address

Nkaifon Perfura, Governor of the Littoral Province, Cameroon

After 5 days of intensive discussion on scientific work — useful exchange of ideas, methods, and results — all 77 of you, who represent 14 West, Central, and East African countries, have arrived at conclusions and recommendations for future research efforts. I hope your thoughts will guide national, and even international programs, toward the realization of adequate production of food and feed for our beloved continent, Africa. I also hope that not only will you as individuals take your message to governments but also the International Society for Tropical Root Crops — Africa Branch will devise a means of more formal contact with national programs to enable them to benefit from the useful experiences that have been presented at this symposium.

Third-World governments have scarce means to achieve their total development plans. Thus, the society must make a strong and justifiable case to enable root-crop researchers to obtain a fair share of the national budget.

I know you have had a difficult week, but I hope the contribution by the Cameroon government to the finances and organization of this symposium helped to enable you to discuss, without stress, your work. I hope also that you enjoyed your stay in Cameroon.

I now have the reluctant pleasure of declaring closed this Second Triennial Symposium of the International Society for Tropical Root Crops — Africa Branch. Again, long live African international collaboration; long live the United Republic of Cameroon.

INTRODUCTION

PRODUCTION POTENTIALS OF MAJOR TROPICAL ROOT AND TUBER CROPS

E.V. DOKU[1]

In comparison with the temperate regions, the tropical environment has lower solar-radiation levels, shorter photoperiods, and, hence, a lower potential productivity. Productivity of cassava, yams, sweet potato, and cocoyams, the four most important tropical root and tuber crops, has other constraints as well: inadequate water supply (in arid areas with optimal solar-radiation levels); pests and diseases; long maturation; and difficult-to-harvest roots and tubers with poor keeping quality.

Research so far has been insufficient to break the numerous bottlenecks, although there is great promise from exploration, conservation, identification, evaluation, and breeding of germ plasm and some high-yielding, adaptive, pest- and disease-resistant varieties have already been developed for distribution throughout Africa. Although yields of the highest yielding varieties currently available are only about one-third to one-half of estimated potentials, recent research on the continent is rapidly amassing knowledge with a concomitant crop-improvement achievement in the following order of priority: cassava, sweet potato, yam, and cocoyam. By the end of the decade, yield levels of commercial varieties of the four crops should approach their potential.

Crop growth and production depend upon the interaction of a population of plants (the crop) and the environment (atmosphere and rhizosphere) in which the crop grows. Each environmental factor may impose a limitation on productivity, and, conversely, increased productivity may arise from a cultivar's ability to overcome the limitations imposed by a single factor or set of factors.

Most of the factors of the rhizosphere — e.g., soil-nutrient status, moisture levels, salinity, pH, physical condition, etc. — can be dealt with agronomically or genetically. The factors of the atmosphere, however, cannot be so easily altered, and plants must be developed to perform under prevailing atmospheric conditions, of which the most important is solar radiation. Van der Paaw (1956) considered that atmospheric factors like CO_2 and temperature do not contribute much to yield fluctuations, as these are determined more or less by other factors such as water supply and mineral nutrition.

Because of cloudiness and high humidity of the tropical atmosphere, daily solar-radiation levels fall in the range of 300–500 cal/cm^2 — only about 0.2–0.3 of the peak radiations (about 1.2 cal/cm^2/minute) observed under the clear skies in desert environments in the tropical and subtropical regions where water is the limiting factor in crop production (Loomis and Rapoport 1977). Tropical environments are further limited by short days (10.5–13 h).

In contrast, at higher latitudes in the temperate zone, daily radiation totals of 500 cal/cm^2 are common during the long summer days, a combination that favours high biomass production. Compared with the temperate regions, therefore, the tropical environment sets a lower limit to productivity. Because of favourable temperatures year round, the tropical regions have an advantage in production of perennial crops and long-season crops such as cassava, yam, and cocoyam. However, the long maturation of such crops makes them inefficient, as yields per unit of land and time are bound to be low.

De Wit (1965) estimated that the gross daily production of dry matter under average conditions of cloud cover (half the sky) was potentially 275 carbohydrate equivalents/ha (i.e., 1.1×10^6 cal/ha), whereas De Vries et al. (1967) estimated the net potential to be half that amount (5.5×10^5 cal/ha). Use of improved varieties under conditions of good husbandry (Watson 1947) would result in yearly production levels of 140 t/ha for cassava and yam and 200 t/ha for sweet potato and cocoyam. The highest levels for these crops so far are only one-half or one-third of these yield estimates.

[1] Crop Science Department, Faculty of Agriculture, University of Ghana, Legon, Accra, Ghana.

Yield Determinants

Only a fraction of a plant's total dry-matter production (biological yield) is represented by the economically useful product (i.e., the root or tuber). Crop yields have been shown to depend upon the photosynthetic capacity of the leaves (source); the capacity of the plant to translocate assimilates from the source to the grain, root, tuber, etc. (sink); and the capacity of the sink to attract, capture, and store assimilates in the desirable form.

The ability to transform a high fraction of biological yield into economic yield is, therefore, the key to the realization of yield potential. Under every atmospheric condition, foliage architecture and photosynthetic capacity are the principal factors that affect primary productivity (biological yield) (Loomis and Rapoport 1976). The nature of the foliage cover is important in determining the efficiency with which solar radiation is used in primary production (Loomis and Williams 1969), and leaf-area index (LAI) has generally been used as an index of photosynthetic capacity. Because of changes in LAI with stage of development of a crop, leaf-area duration (D), the integral of LAI over time, was suggested by Watson (1947) as a measure of the plant's ability to produce and maintain its leaf area and hence its opportunity for assimilation.

A number of workers, including Williams et al. (1965) and Shibles and Weber (1966), suggested that the time integral of percentage solar-energy interception is better than LAI and D as an index of photosynthetic capacity. Solar-energy interception has, however, not been used to any extent as a determinant of photosynthetic capacity of crops, and Chapman (1965), Enyi (1972a), and Ferguson (1977) have concluded that LAI and D are the most important physiological determinants of yield from root and tuber crops.

Genetic determinants of yield include efficient utilization of the resources of the rhizosphere, resistance to the numerous field and storage pests and diseases, shelf-life, etc. The degree to which genetic variability in these attributes can be exploited by breeders for the improvement of the crop is the yardstick by which to judge current production levels as well as prospects for the realization of the potential. The interrelationships between physiological determinants and yield are little researched, even though understanding them is the key to optimal efforts in genetic improvement. In other words, a breeder needs to know how the plant is interacting with the environment before he or she can efficiently improve on the plant's ability to cope. More work, therefore, needs to be done. Considerable work has, however, been done on the development of pest- and disease-resistant varieties with remarkable results.

Pests, Diseases, and Agronomic Problems

Work carried out at the International Institute of Tropical Agriculture (IITA) as well as in many countries has established firmly that pests and diseases constitute major constraints to the production of root and tuber crops in Africa. Accordingly, the bulk of IITA research is geared toward finding solutions to this problem, through the development of resistant varieties as well as suitable cultural techniques and other control measures.

Other serious constraints include weed competition; the long maturation of cassava, yam, and cocoyam; difficult-to-harvest roots and tubers of cassava and yams; and the rather short postharvest life of all root and tuber crops, cassava in particular.

Research Highlights and Achievements

Cassava

In studies of physiological determinants, Enyi (1972a) found that 75% of the variation in cassava yields could be attributed to differences in D. However, Holmes and Wilson (1977) found that, although high leaf production and retention were important determinants of both total dry-matter and root yields in six West Indian cassava cultivars, high root yield was not necessarily correlated with high rate of leaf production and retention. One of the cultivars, Maracas Black Stick, produced high yields and had a high harvest index (HI) despite low production of leaves. It was suggested, therefore, that HI should be used in screening cultivars for high yield. The need to understand source–sink relationship as an important character in crop selection is implicit from these results. Cassava flowers and fruits readily, and techniques for hybridization and breeding have been worked out (Hahn et al. 1979; Hahn 1982a). Therefore, determining the genetic bases for these physiological determinants should be easy and would facilitate further breeding work.

The low yields (about 7 t/ha in 12 months) of cassava in Africa can be attributed largely to

diseases and pests (Hahn et al. 1979, 1982a). The major diseases and the yield losses attributed to them are: cassava mosaic disease (CMD) 20–90%; cassava bacterial blight (CBB) up to 100%; grasshopper 60–80%; cassava green mite (CGM) up to 40%; and cassava mealybug (CMB) up to 100%.

Cassava is also liable to weed infestation, especially during the first 10–12 weeks, and Godfrey-Sam-Aggrey (1978) reported 20% yield loss if first weeding were delayed by more than 2 months. In extreme cases, yield losses are total. Soil temperature, moisture, and rooting depth also affect root yield (Hahn et al. 1979). Soil temperatures higher than 30°C at 5 cm below the surface occur frequently in the field; hence, yield reduction can be considerable.

In spite of the common observation that cassava is fairly drought-tolerant, significant yield reductions have been observed under drought conditions (Shanmugavelu et al. 1973). High soil temperatures strongly interact with moisture stress to reduce yields even further.

The IITA root and tuber program has screened several hundred clones for resistance to grasshopper, and some tolerant clones whose shoots and stems are not damaged have been selected for further work. One *Manihot* species from South America has also been identified as showing resistance to the mealybug, and a breeding program involving this resistant species will soon start. A biological control program in collaboration with the Commonwealth Institute of Biological Control (CIBC) is already under way, and parasites and predators have been released in Zaire. Preliminary observations indicate that the program will be successful. Chances of finding resistance to the green mite are also high, and already five tolerant clones have been observed in Tanzania. Pubescence and growth vigour are strongly associated with green-mite resistance.

Major success has been achieved in controlling CMD and CBB, with the breeding of resistant varieties, all of which yield well, have good consumer acceptance, and are low in HCN. IITA-bred varieties TMS 30572 and TMS 30555 have yielded more than 40 t/ha since 1973 without fertilizer and have shown adaptation over 26 Nigerian environments differing in soil, rainfall, and other climatic conditions. Both are moderately resistant to CBB and CMD, and their progeny have performed similarly well in Sierra Leone, Gabon, Zaire, Zanzibar, Seychelles, as well as in India (Hahn 1982a).

Two other new varieties TMS 30001 and TMS 30395 are very resistant to both CBB and CMD and give reasonable yields (IITA 1978). TMS 30001 has been recommended for intercropping because it branches higher than most cassava cultivars. Clone 58308, which has been found to have high combining ability for resistance to CBB and CMD, good yield, and low HCN, is a good parent to use in breeding new varieties.

These improved clones have outyielded local Nigerian varieties by a factor of 2–18 under epiphytotic conditions, especially with CBB. When intercropped with maize, they yielded three times that of the local (Hahn et al. 1979). They have also outyielded, by up to 16 times, local varieties in several African countries including Sierra Leone, Tanzania (Zanzibar), Zaire, Seychelles, as well as India.

The population-breeding program being carried out at IITA has therefore proved itself. It is now possible to maintain, in vitro, all germplasm material of more than 2000 accessions as well as newly bred varieties, instead of the laborious live maintenance method by regular field planting. Improved material in tissue culture of eight clones has been sent to more than 20 different countries and is available to those who ask for it and satisfy simple, phytosanitary conditions.

Although no selections have been made for improved keeping qualities in cassava, cultivar differences exist in the thickness of the peel and, particularly, in the adherence of the outer skin to the inner skin (Doku 1980). These characteristics, in addition to the various inner and outer skin textures and colours, could be indicative of cultivar differences in resistance to wounding, and, hence, to primary and secondary infections during storage. Booth (1975) has noted cultivar differences in the time to the onset of deterioration and in the rate at which deterioration advances.

Booth's (1975) clamp-and-box storage techniques prolong storage life of roots by up to 8 weeks. The indications, therefore, are that varieties with desirable root–skin characters could be stored according to Booth's clamp-and-box techniques far beyond 8 weeks.

Yams

The major physiological factors limiting yield of yams have been found to be the mutual shading of leaves and the low capacity of the tubers to attract assimilates during early growth. Highly positive correlations have been found between D and tuber yield (Chapman 1965 for *D. alata*; Enyi 1972a, 1973 for *D. esculenta* and *D. rotundata*). Because of the excessive shading, D in

yam is low and a major source of yield limitation, particularly in *D. alata* and *D. rotundata*. As regards partitioning of assimilates and sink strength, recent work by Okoli (1980) on *D. rotundata* and *D. alata* indicates that high HI per se does not necessarily produce high harvestable tuber yields. Therefore, in breeding programs, high HI should be considered together with high dry-matter yields, large photosynthetic area, and high photosynthetic efficiency.

The progress in effecting hybridization and seed setting has been slow and has curtailed exploitation, on a large scale, of genetic differences in physiological yield determinants. Although methods of promoting flowering and of controlling sex expression are yet to be worked out, recent work reported by Akoroda et al. (1980) and Wilson (1982) indicates that it is possible, by methods of artificial pollination, to raise large numbers of seedlings. This means that, for all cultivars except the nonflowering types, superior characters can be selected and recombined and their genetic bases can be worked out, as Hahn (1977) reported in his preliminary work on source–sink relationships in the sweet potato. Breeding for physiological characters that improve yields in yams should, therefore, not be far off.

As is the case with cassava, the most important factors limiting yam production are diseases and pests. Nematodes — *Scutellonema, Meloidogyne*, and, to a lesser extent, *Pratylenchus* — cause serious damage both in the field and during storage. Foliar diseases including yam virus and leaf spots such as *Cercospora* and *Colletotrichum* reduce yields in some areas, and the yam tuber beetle *Heterolygus meles* causes conspicuous damage. Storage losses caused by nematodes, fungal and bacterial rots are high and are further increased by rodent attack, insect damage — scale insects and mealybugs — and respiration and sprouting (Wilson 1982).

Another limitation to productivity is the high production costs — largely a reflection of labour requirements at planting and harvesting; staking; and the large amount of planting material required.

Researchers, therefore, need to breed or select yams that, in addition to having high tuber yields and good culinary qualities, have resistance to pests and diseases and store well. Other focuses should be characters that will eliminate staking; reduce the amount of planting material; and facilitate mechanical harvesting — i.e., several small tubers that are shallow setting, oval, round, and uniform with a tough (thick) periderm. (A thick periderm would also reduce postharvest losses.)

There are not many *Dioscorea* species or cultivars with these desirable characteristics, and plans in Ghana are to start mutation breeding in collaboration with the International Atomic Energy Agency, Vienna, with the principal aim of obtaining self-supporting, early maturing mutants. Knowledge of flowering, seed set, pollination, and hybridization techniques is already available and is being expanded. Therefore, incorporating desirable characters from the mutants in breeding populations should not be difficult.

In the meantime, the genetic diversity exhibited in seedling populations as a result of artificial hybridization is being exploited by several countries, and, to date, IITA has tested more than 60 000 genotypes, mainly of *D. rotundata* seedlings, in several locations representing different cultural and ecological conditions. Selections are being made under both staked and unstaked conditions for yield, earliness, pest and disease resistance, tuber conformation, quality, and storability. Considerable genetic variation has been reported for all these characters (Sadik and Okereke 1975).

Hahn and Hozyo (1980) believe that it should be possible to obtain varieties with fresh tuber yields of 10–20 t/ha attainable in 6–11 months and that 40 t/ha can be obtained during similar periods with good cultivars (female *D. rotundata* plants, for example) and management.

Of all the *Dioscorea* species, *D. dumetorum* can be stored in the ground the longest without adverse effects but hardens within 3–4 days after harvest. Farmers, therefore, leave the tubers in the soil and harvest a few at a time. There are cultivar differences in the hardening character, and a Cameroon local cultivar, Muyuka, can be harvested and kept for up to 2 months without hardening. Since Muyuka does not yield so well as other cultivars, a hybridization program is envisaged to combine the good storage qualities of Muyuka with a high-yielding cultivar Jakiri. Both cultivars flower and fruit readily, and the program is expected to yield good results (S.N. Lyonga, personal communication).

A rare species, *D. liebrechtsiana*, that is indigenous to Cameroon has also been found to store well in the ground. This long-season yam continues to grow during the dry season but may be harvested after 11 months. The periderm of the tuber is very thick and corky, which protects the tuber almost indefinitely from rotting. Yields are average, and consumer acceptability is good.

It should be possible through interspecific hybridization to incorporate the excellent qualities of this species into the more popular *D. rotundata–D. cayenensis*. *Dioscorea liebrechtsiana* has not been observed to flower, and methods of flower induction must be found before a breeding program can get under way (S.N. Lyonga, personal communication).

As nematode attack in the field predisposes tubers to storage rots, tubers of *D. rotundata* seedlings are routinely screened at IITA, Ibadan, for resistance to nematodes. Since 1979, more than 5000 seedlings from six resistant breeding lines have been screened. Four IITA accessions have been found to be reasonably resistant. They are TDr 779, TDr 820, TDr 817, and a Nigerian local cultivar Nwapoko, which yields between 25 and 30 t/ha.

Water yams (*D. alata*) have a reputation for storing very poorly. However, a few cultivars — generally round with firm pale-purple flesh (very much like some cultivars of cocoyam) — have remained intact in storage for more than 6 months, free from pests and diseases and without sprouting.

With the available knowledge of artificial pollination, hybridization, seed germination, care of seedlings, etc., the stage is set for the incorporation of all these excellent storage characteristics into existing cultivars.

Sweet Potatoes

In an attempt to overcome one physiological constraint to high yields of sweet potatoes, researchers at IITA screened more than 10 000 sweet-potato genotypes (Sadik 1973) for low CO_2-compensation concentration as an index of photosynthetic efficiency (PE). However, plants selected as having high PE did not produce significantly higher biomass than did genotypes with lower PEs. Later, PE was observed to be less important than assimilate distribution as a limiting factor to high yields. Genetic studies on crosses involving clones with high and low PEs revealed that PE was controlled largely by non-additive genes as well as other factors inversely related to it (Hahn 1977).

The major constraints to sweet-potato production in Africa are weevils and viruses. Work at IITA, in particular, has concentrated on these two constraints. Yield reduction from viruses has been estimated to be 78–80% in Nigeria (IITA 1975) and 57% in Uganda (Mukiibi 1977). Weevils damage both tubers and leaves in the field and also reduce quality, storability, and market value.

The IITA improvement program, which was initiated in the early 1970s with the evaluation of more than 10 000 seedlings, has accomplished much. Seeds from improved populations have been sent to many African countries, and currently material in tissue culture is being widely distributed. More than a dozen resistant clones, which yield 13–30 t/ha and are acceptable to consumers, have been bred. Of the four most virus-resistant clones developed, three are among those selected for weevil resistance (Terry 1979).

At IITA, weevil resistance has been found to involve delay in larval development on roots. Also, resistant roots have been observed to be relatively high in dry matter and low in protein and sugar. Biological analyses are in progress to ascertain the substances responsible and, hence, the mechanisms involved in resistance (Doku 1980).

In Cameroon, there is a weevil-resistant cultivar with a pinkish skin and gray–white flesh that produces a lot of mucilage. The role of mucilage in weevil resistance is, therefore, being investigated (Doku 1980).

When the factors responsible for resistance are found, breeding for weevil resistance should be possible by selecting and crossing the appropriate genotypes from seedling or clonal populations. Therefore, the possibility to increase yields beyond 30 t/ha is good. Research to find solutions to the sterility–incompatibility phenomenon within the species must be intensified to widen the scope of hybridization and, hence, the genetic base of available varieties.

Cocoyam

The relationships between physiological determinants and yield in both *Xanthosoma* and *Colocasia* have been studied by Moursi (1954); Purewal and Dargan (1957); Enyi (1967a,b, 1968, 1977a,c); Ching (1970); Ezumah and Plucknett (1977); Abit and Alferez (1980); Sivan (1980); and Wilson (1980, 1981b). Almost all of this work was done in Asia. In both species, leaf area, LAI, and D were found to be closely related to yield, and strong positive correlations were reported between corm or cormel yields and leaf area.

To exploit the full potential of both species, Wilson (1981b) urges the selection of plants with large canopies that develop rapidly and last a long time. Also important is leaf angle (or leaf orientation) that varies from 47° to the vertical to almost horizontal (70–80°), as well as petiole length and angle. Petioles of some cultivars are

very large and may constitute an unnecessary sink in competition with corms and leaves that are the important economic products. Ability to control weeds and erosion has also been found to be an important physiological attribute.

Recent developments in techniques of inducing flowering with gibberellic acid (Alamu and McDavid 1978a,b) have now opened the way for geneticists to study important yield-related characters in *Xanthosoma* and *Colocasia* and for breeders to combine the useful characters to produce elite varieties. Several improvement programs based on hybridization and selection are already under way.

Field and storage rots are the major constraints to cocoyam production. Several organisms appear to be associated with rot, and yield losses have been estimated to be between 40% and 90% (Arene and Okpala 1981; Muduewesi et al. 1981; Okeke 1981).

Recent research in Nigeria and Cameroon has revealed potential sources of resistance among *Xanthosoma* hybrid seedlings from crosses between local and Caribbean accessions. This indicates that resistance may be present within the gene pool in both countries. Efforts should be made to select for the most suitable accessions to form the basis of a comprehensive breeding program for disease resistance.

Current production of any crop is the culmination of several processes that start with planting and end with the consumer. The processes include germination (sprouting in the case of asexual propagules); crop establishment; competition with weeds; interception and utilization of solar energy — hence, photosynthesis and biomass production; partitioning of biological yield into economic yield; tolerance or resistance to field and storage pests and diseases; resistance to damage and deterioration during harvesting, transportation, storage, retailing, etc.

These desirable attributes should remain fairly stable in elite varieties for many years under the various environmental conditions in which the crops are grown. The degree of excellence at every step in the process determines yield. Productivity, therefore, involves more than economic yield per se, or its immediate precursors (biological yield and harvest index). It is a complex interaction grounded in ontogeny. Knowledge of each attribute that affects yield is necessary to push current production levels nearer to the potential. Considerable work has been done through selections for yield per se, followed by selections for resistance to field pests and diseases. The efforts have resulted in phenomenal increases in the yields of cultivars. However, work on physiological characters related to yield should be intensified and serious attention paid to the improvement of postharvest characteristics, without which most of the improvements in yield will be eroded before reaching the consumer.

The extent to which activities in crop improvement, agronomy, crop protection, farming-systems research, etc. have succeeded in tapping potential could be summarized according to:

- Exploration for and maintenance of genetic diversity within the species and related wild species whose useful genes can be incorporated into the cultivated species;
- Knowledge of the strategy of economic-yield attainment and the development of suitable agronomic practices to overcome production bottlenecks;
- Research capability to develop productive and adapted varieties through improved breeding and selection techniques;
- Maintenance and distribution of improved varieties together with a package of appropriate production techniques; and
- Overall performance of improved varieties in the various growing areas vis-à-vis the numerous production constraints — i.e., pests and diseases, drought, etc.

The results of efforts so far range from poor to excellent, with cassava clearly the leader, followed closely by sweet potatoes, and cocoyams being the poorest. However, for all these crops, solid foundations are being laid under the leadership of IITA, the quality of whose work is gradually being appreciated and adopted by all countries. My forecast is that, by the end of the 1980s, we will get close to the production potentials estimated for these crops.

POTENTIAL UTILIZATION OF MAJOR ROOT CROPS, WITH SPECIAL EMPHASIS ON HUMAN, ANIMAL, AND INDUSTRIAL USES

D.G. COURSEY[1]

Root crops in developing countries are mainly used for human food. Most are still grown by small-scale farmers, who operate within the subsistence economy, with only limited off-takes of produce to the market economy supplying the rapidly growing urban centres. With cassava in much of Latin America, yams in West Africa and the Caribbean, and taro in the Pacific, a trend exists, and may be expected to increase with further urbanization, toward semicommercial or commercial production, together with the development of more sophisticated marketing systems. Yams and, in most circumstances, taro, other aroids, and minor root crops command too high a price for significant amounts to be available for uses other than human food, although peelings, waste, etc. are used as animal feed within subsistence economies. Cassava is in a completely different category, the costs of equicaloric amounts being only about one-fifth of those of yam. Similarly, sweet potato, with two to four crops per year, is productive and like cassava is seldom a preferred food. These two crops can, therefore, supply substantial surpluses beyond food demands; the former, especially, is already being exploited for animal feed, edible and industrial starch, and other derived products. Although alternative uses of tropical root crops will probably increase, their primary role is likely to remain as human food in producing countries.

"Tropical root crops" could be defined in many ways, but most workers accept that the phrase refers to staple foods grown in tropical or near-tropical conditions where the edible organ — root, stem, tuber, etc. — is subterranean (hypogeous) (Table 1). I will confine my discussion to those that are used as major providers of carbohydrate in the diet and largely take the place of grains — wheat, barley, maize, sorghum, millets, and rice — in other agricultural economies.

At the sixth international symposium on tropical root crops in Lima, Peru, in February 1983, considerable criticism was directed at the value of existing statistics, the theme being that where a substantial proportion of a crop is grown within a subsistence economy, as applies to so much of tropical agriculture, a degree of underreporting of production is likely to occur. However, the current overall pattern is not vastly different from that reported more than a decade ago (Coursey and Haynes 1970), allowing for increases in population and advances in agricultural practice.

[1] Deceased 31 December 1983; formerly at Tropical Development and Research Institute, London, England.

CIRCUMSTANCES AND TYPE OF UTILIZATION

Before proceeding to the main topic, I believe it appropriate to set the scene of production and also refer to some of the social changes that relate to root-crop utilization. First, the ecological conditions of growth. The work of Flach (1979), following preliminary studies by de Vries et al. (1967), indicated that root crops are produced mainly in the humid equatorial areas and the subhumid savannas adjacent to the equatorial zone. There are exceptions, however, particularly the potato, which, although native to highland equatorial tropics in the Andean altiplano, has been developed most successfully as a temperate crop; only recently is it returning to the tropics. The sweet potato is a short-term crop that matures in 3–5 months and is extensively grown in subtropical or warm temperate areas.

Tropical root crops were essentially products of subsistence agriculture until 2 or 3 decades ago. A large proportion of the crops was consumed by the farmer's immediate and extended families; only modest quantities were taken for marketing, even for exchange in neighbouring villages. Outside Latin America, few substantial

Table 1. Tropical root-crops production in developing countries.

Common names	Botanical names	Production (10^6 t/year)	Edible organ
Cassava (tapioca, manioc, mandioca, yuca)	*Manihot esculenta* Crantz (often incorrectly, *M. utilissima* Pohl.)	127	Root
Yam (igname, ñame)	*Dioscorea rotundata*, *D. cayenensis*, *D. alata*, *D. esculenta*, *D. dumetorum*, minor *Dioscorea* spp.	18–22[a]	Stem, hypocotyledonary tuber
Sweet potato (batata)	*Ipomoea batatas*	18[b]	Root tuber
Potato (white, Irish)	*Solanum tuberosum* (and *S. tuberosum* × *S. andigenum* hybrids)	36[b]	Stem tuber
Taro (dasheen, eddoe, old cocoyam)	*Colocasia esculenta*	4–6[a]	Corm, cormel
Tannia (ocumo, new cocoyam)	*Xanthosoma sagittifolium*	1–2[a]	Corm, cormel
Elephant yam	*Amorphophallus campanulatus*	1[a]	Corm
Giant taro	*Cyrtosperma* spp., *Alocasia* spp.	1[a]	Corm

[a]My estimate.
[b]FAO (1982a) estimate does not include production in China.

cities existed in the root-crop-growing areas of the tropics, and only limited urban demand was generated. This situation has changed rapidly over the last few decades, with the urban population growing about twice as fast (5% compared with 2.5%) as the total population.

This not only implies an increase in the need to supply the conurbations but also a relative (although not absolute) reduction in the food-producing rural population. Although in many parts of Africa the traditional subsistence pattern may be expected to persist for a considerable period, the trend toward urbanization can be expected to continue.

FAO (1982b) has estimated that, whereas only 28% of inhabitants of the developing world lived in urban centres in 1975 (in itself a great increase on figures for 10 years before), by the year 2000 the figure can be expected to reach 44%, i.e., nearly half the population of the developing world. The transportation of perishable material such as root crops from rural to urban centres is a much more difficult problem than the transportation of grains and other durables. The technical problems associated with long-distance transport of perishable food crops such as root crops have been discussed elsewhere (Coursey 1983a). Transportation considerations are inextricably linked to processing, as transporting food that has low moisture and high stability is obviously more facile than moving a bulky, awkward, easily damaged material that contains substantial amounts of water and waste.

The mechanized processing of root-crop products, particularly yam and cassava, has come, especially in West Africa, to be regarded as a universal panacea for transportation problems: in fact, very little practical success has been achieved. Many factors, mainly of an economic nature, are involved as farmers are reluctant to sell their crops for processing to a large factory whose presence they often regard as alien and suspect. Organoleptic problems have arisen, as the products of some of the pilot-scale operations have not accorded with traditional tastes. New attempts are being made to mechanize processing, but no substantial commercial success has yet been obtained. This contrasts markedly with the situation in developed countries, where substantial quantities of both *Solanum* and sweet potatoes are processed into flakes or powders that can be easily reconstituted with water and also into crisp, deep-fat-fried and dehydrated products for which the tropical root crops are also quite suitable. Such fried products, mainly from yams, are indeed manufactured, especially in the Caribbean but, so far, only in cottage industries. Brief mention must be made of the success in Hawaii of producing a traditional foodstuff, poi, from *Colocasia*

by a partially mechanized process; in developed countries there is greater emphasis on the production of convenience foods.

The traditional storage techniques that are entirely adequate in subsistence agriculture (Coursey 1982) may not apply to situations where remote urban markets are being supplied. In spite of this, the extreme ingenuity of farmers and intermediaries in dealing with traditional crops must never be forgotten: when the first European contacts were made with West Africa in the late 1400s, coastal settlements, such as the modern Bonny, in Nigeria, were being supplied with yams brought "hundreds of leagues" by canoe by inland waterways (Coursey 1967b).

A topic that has received much attention of late is the incorporation of root crops, usually for economic reasons cassava, into composite flours for making bread or other bakery products. Many investigations have been done, and, from the technical point of view, there is usually no difficulty in replacing 10–30% of the constituents with root-crop material for bread making and even larger amounts for pastry and similar products.

The factors that have prevented the widespread adoption of composite flours have been economic rather than technical and are similar to those that affect almost any large- or medium-scale operation based on root crops in developing countries, i.e., the difficulty of obtaining adequate supplies of raw material at an economic price. Indeed, in some countries, bread containing cassava is favoured and commands a higher price than conventional bread, and attractive bakery products can be made with yam and sweet potato where economically possible. The basic requirements for programs based on composite flour have recently been discussed by Crabtree and James (1982), and Dendy et al. (1971) reviewed earlier work. The use of cassava, economically the most attractive material, has been discussed by Crabtree et al. (1978), introducing the interesting concept of blending peeled, mashed cassava with wheat flour to eliminate the drying stage of the cassava before its utilization, as it appears illogical, unless shelf-life or transport is a consideration, to dry a material and then add water to the dough that is being prepared.

All that has been said has indicated that the major use of tropical crops is as human food: this is in fact the case.

The second most important use of tropical root crops is animal feed, but this is distinctly limited. In many societies, crops are too highly valued as human food to be diverted to other purposes (other than peelings and wastes, which could be a valuable by-product if successful factories were ever established), and it is only the cheaper crops that can be used for nonfood purposes.

The only other industrial use of the tropical root crops is the manufacture of starch, which is the major constituent of the economic organs of the crops concerned. In some countries, commercially successful starch industries using high technology have been established, usually based on cassava as the cheapest raw material. In some cases, such as Thailand, factories are operating to produce starch for export, whereas in other countries, such as Nigeria, import substitution is the main goal. There is also considerable production of starch at artisanal levels for nonfood use, especially the starching of clothes after laundering (Jones 1983).

In Japan, sweet-potato starch and, in Europe, potato starch are important industrial-scale commodities. There is no inherent reason that starch, especially from sweet potatoes, should not be manufactured in larger quantities in the developing world. Other possibilities exist for proceeding from starch to glucose syrup for fermentation, but only one or two industrial operations have been established for this purpose. Phillips (1974) has estimated that only 1% of cassava production is diverted into industrial uses other than animal feed, and, for the other root crops, the figure would be substantially less.

Cassava

Not only is cassava the most important root crop of the tropics, its production (Table 2) being much greater than all others put together; it is also the most ubiquitous and is grown almost everywhere where ecological conditions permit. It is essentially a tropical crop, although some cultivars can withstand light frost, e.g., in southern Brazil, parts of Argentina, and Zambia (Montaldo 1979). Traditionally, cassava has been processed at an artisanal level, often into dried products; the history of such processing goes back probably about 4000 years to the domestication of the crop in northern South America (Lancaster et al. 1982). The various methods of utilization as food have been fully reviewed recently by Lancaster et al. (1982). A very large proportion of the total crop is consumed in the production areas, although in countries such as

Table 2. Cassava production and utilization in major producing countries (FAO 1982a).

	Production (10^6 t)	% of global total	Production (kg/person)
Total developing countries	127.261	100.0	38.2
Brazil	25.050	19.7	200.0
Thailand	17.900	14.1	371.9
Indonesia	13.726	10.8	91.2
Zaire	13.000	10.2	446.7
Nigeria	11.000	8.6	138.1
India	5.817	4.5	8.3
Tanzania	4.650	3.6	251.1
Vietnam	3.400	2.6	61.9
China	3.276	2.5	3.3
Mozambique	2.850	2.2	264.9

Brazil and much of West Africa, where traditionally it is processed into dry products, substantial long-distance trade in the products exists (Coursey 1978a; Lancaster et al. 1982). The toxicity of many cultivars of cassava and the inherent perishability of the roots provided a double incentive to the development of simple processing techniques, modifications of which are now used in very many parts of the world. In West Africa particularly, a great part of the cassava crop is processed and traded in the form of gari or sometimes other dried products (Coursey 1978a). Although the use of cassava as food is continuously being condemned on the basis of its low-protein and high cyanogenic-glucoside contents, both these factors have probably been greatly overrated. Cassava should be regarded as a source of carbohydrate and little else (small quantities of vitamins and minerals) and should be used, like any starchy food, in a diet that is adequate in protein from other sources. Only in extremes of poverty where people are forced to eat cassava and little else does serious protein deficiency or cyanide toxicity arise (Cooke and Coursey 1981; Delange and Ahluwalia 1982). Nevertheless, the increase in kwashiorkor in Africa and other parts of the world may be partly caused by displacement of the protein-rich yam by the much cheaper cassava. Similarly, toxicity may well have been substantially exaggerated. First, there is a wide range in cyanide content among cassava cultivars, and the widely held belief that cyanide content is directly related to plant vigour appears to have little foundation in fact. Chronic cyanide poisoning tends to be associated with famine when intake of protein and sulfur is insufficient. Furthermore, it is most likely to happen in areas where soil deficiencies induce iodine deficiency in the population, as the thiocyanate formed in the body during the detoxification of the cyanide can interfere with iodine metabolism (Nestel and MacIntyre 1973; Cooke and Coursey 1981; Delange and Ahluwalia 1982).

Cassava is unique among tropical root crops in that it has substantial potential for use as animal feed. Dried cassava, in the form of meal and chips, has been exported in small quantities from many tropical countries, including Brazil, Madagascar, Indonesia, and Thailand, for many years (ICM 1949), but the total amounts appearing in trade internationally were comparatively limited and quality was usually exceedingly poor until recently. In the mid 1960s, Thailand started to develop an export trade in dried cassava products, initially in dried chips and the meal prepared from them. This trade was initially almost entirely with the "Old EEC" (European Economic Community) countries, and, in fact, Germany, Belgium, and Holland are still the main importers. This market was created artificially by factors within the Common Agricultural Policy (CAP) of the EEC, which enabled substitutes for grain to be imported at low duty. These exports rose from less than 0.5×10^6 t of dried products annually in 1962 through 1.5×10^6 t 10 years later to $5–7 \times 10^6$ t in the later 1970s or early 1980s. During the same period, a change in practice occurred, and, now, dried, ground cassava is also pelleted under heat and pressure with the addition of a binder to make it more appropriate for incorporation into animal feed and also to ease shipment (Phillips 1974; UNCTAD 1977; Walters 1983). Thailand is an exception to the rule in that little of its cassava is used for local human food; indeed Thailand has been able to build up this substantial export trade largely *because* there is minimal competition from local food markets. It is exceedingly difficult to support any cassava-based operation at the industrial or export level in countries where such a demand exists. During the late

1960s and early 1970s, much interest was shown by official and commercial bodies in many tropical countries in establishing exports of dried cassava to Europe, but none of these projects had any real hope of success in view of the competition in price from local markets for either fresh or traditionally processed cassava. A small proportion of the cassava pellets in international trade derives from Indonesia, but the market is dominated by Thailand, which has made massive investments in port facilities for bulk handling. Cassava is the third largest of Thailand's exports, and there is serious concern there that, through changes in the economic policies of the EEC, a quota system will reduce cassava imports from nearly 7×10^6 t in 1981 (Braude 1982) to 5×10^6 t in 1984 and 4.5×10^6 t in 1986.

Along with the export of cassava products for animal feed, there is a growing interest in exporting fresh cassava for human food to urban centres either in producer or neighbouring countries or in countries where there are cassava-consuming immigrants. A substantial industry exists in Latin America, particularly Costa Rica, to supply North American and, to a lesser degree, European markets with deep-frozen, peeled cassava roots, and these can be obtained in most supermarkets where there are immigrant populations. At the same time, a smaller amount of fresh cassava roots packed in absorbent material is exported. It is now possible to buy fresh cassava roots in British urban markets, something that could not have been done even a few years ago.

Cassava is used as animal feed in many producer countries, especially in Latin America, and in general satisfactory results have been obtained, although problems, particularly of acceptability, still exist (Nestel and Graham 1977). The pig in particular seems to be exceedingly resistant to cyanide, and the incorporation of cassava into pig rations appears to present few problems. The burgeoning poultry industry of the developing world presents another opportunity for cassava's use as animal feed. The problems will probably be more economic than technical in any country where a substantial demand for cassava for human food exists. Also, if cassava is being introduced into compound feed in place of barley or maize, larger amounts of protein will have to be incorporated to make up for the minimal amounts of protein contributed by the cassava to the ration.

Cassava-based starch industries have been set up both at industrial and, much more widely, at artisanal levels in many countries of the world, generally using some form of wet extraction and settling process (Phillips 1974; Jones 1983; Walters 1983). This utilization is currently only about 1% of the total world crop and is not likely to increase very substantially in the near future. One or two factories exist in developing countries that take the starch a further stage to glucose syrup, but any industrial activity in countries where cassava is eaten will always suffer economic problems associated with competition from local food markets.

Since the rapid escalation of energy costs, especially liquid fuel, considerable attention has been given to cassava as a source of ethanol. Brazil, in particular, has put enormous efforts into the production of alcohol for power purposes from biological resources, although more effort has been put into sugarcane than into cassava: there is one plant operating in Brazil utilizing cassava, whereas many utilize sugarcane. The disadvantage in using cassava instead of cane is that it must undergo amylolysis before alcoholic fermentation, but cassava has the advantage of being capable of growing on marginal soils and under poor conditions. Currently, the energy costs of producing a litre of power alcohol from cassava appear to be of the same magnitude as, or even slightly higher than, the calorific value of the product. Thus, this particular use of cassava would make sense only when oil prices have risen higher and the premium on portable liquid energy is greater than it is today (Dominguez 1983).

Yams

Yams are botanically very different from cassava as is their utilization. In all societies where they are major crops, mainly West Africa, Melanesia, and the Caribbean, they are crops of prestige: their cost in equicaloric terms is anything from three to five times that of cassava (Coursey 1967b, 1978b). They are ancient crops and, within the cultures in which they are grown, have acquired a heavy burden of religious and magical significance that hardly applies to any other tropical crop (Coursey 1978b, 1981). In practically all the areas where they are grown, they are the preferred staple food, and this contributes to their high unit cost. Unlike cassava, they need rich soil, a lot of attention in cultivation, and substantial labour in harvesting and storage. Against this background, it is almost impossible to consider yams for any purpose other than human food. The only caveat on this is that, in traditional societies, yam peels and

Table 3. Yam production and utilization in developing countries (FAO 1975).

	Production		Utilization
	10^6 t	% of global total	(g/person/day)
Nigeria	15.00	74.3	652
Ivory Coast	1.70	8.4	695
Ghana	0.80	3.9	222
Togo	0.75	3.7	914
Benin	0.61	3.0	543
Ethiopia	0.27	1.4	26
Sudan	0.26	1.3	47
Papua New Guinea	0.17	0.8	169
Jamaica	0.13	0.7	180
Guinea	0.06	0.3	34

waste are often thrown out to feed livestock, especially goats and chickens. If a yam-processing plant were successfully set up, the use of the peel for animal feed could affect overall economics. Nevertheless, the main purpose of the yam must continue to be to provide human food at, regrettably, increasing real prices.

In spite of many warnings that yam production is declining in West Africa, the best FAO statistics that existed up to 1977, when yam ceased to be counted as a separate crop, suggested that global yam production (essentially West Africa) has increased very slightly (Table 3).

The genus *Dioscorea* contains approximately 600 species, but only a small proportion of these are utilized as food. Probably between 50 and 100 species in all are eaten on occasion, some being collected from the wild and used only in times of famine. World yam production derives mainly from the *D. rotundata–D. cayenensis* complex, from *D. alata*, and from *D. esculenta*. *Dioscorea dumetorum* has special importance in Cameroon. Other species are of substantial local importance. Nigeria alone produces almost three-quarters of the yams in the world, whereas the countries of the "yam zone" — Nigeria, Benin, Togo, Ghana, and Ivory Coast — produce together more than 90%. A number of small countries in which yams are very important, such as Tonga and Barbados, have not been included because their contribution to global production is small. One developed country, Japan, produces approximately the same quantity of yam as Jamaica but grows a temperate species, *D. opposita* (commonly but incorrectly know as *D. batatas*). It is not a staple food in that country but rather is grated and used as a condiment in small quantities with other foods (Kawakami 1970).

Although most of the yams produced are consumed locally, there is a long tradition of movement of yam between rural areas and urban centres in West Africa and between islands in the Caribbean and in the South Pacific (Coursey 1978a).

Appreciable quantities are shipped to developed countries for the use of African and Caribbean ethnic minorities living there. For example, about 8000 t go to Britain annually (Bell and Coursey 1970); originally from Nigeria, now *D. rotundata* and *D. cayenensis* come principally from Brazil and Jamaica, whereas some *D. alata* comes from Barbados. The yam tuber, being a dormant organ, is almost ideally suited for storage and transportation. Only in some Yoruba-speaking areas of western Nigeria and in parts of Ghana is a large proportion of the yam crop processed into dried pieces or meal. Traditional processes involve parboiling yam slices, drying them in the sun, and then pounding them with a wooden mortar and pestle into a coarse flour, known in Yoruba as amala. In other yam-growing areas, such yam flour is made only from yams that are found to be rotten at the time of harvest or that, for some other reason, are unsuitable for storage or immediate use. Such flours, however, are made in almost all yam-growing areas of the world (Coursey and Ferber 1979).

Yams are used in many culinary ways, with great differences in species, and even cultivars, on account of the wide variation in starch granular and rheological properties. The most favoured yam-based food in most of West Africa is the heavily pounded dough known as fufu, which is best when prepared from *D. rotundata*, with its high starch viscosity and gelatinization strength. Fufu suffers from what appears to be a rapid drying out within a few hours of preparation but what is actually an effect of the ex-

tremely rapid retrogradation of yam starch compared with other starches (Coursey and Ferber 1979; Coursey 1983b). People accustomed to European diets often consider that *D. alata* tastes better than the *D. rotundata–D. cayenensis* group because it (and *D. esculenta*) can substitute for potato and is not greatly dissimilar. The *D. rotundata–D. cayenensis* yams, however, have distinctive flavours and textures that make them attractive to those accustomed to them. *Dioscorea dumetorum* is greatly liked among most West Africans for its fine flavour, although it needs to be processed to remove the alkaloid present; it is soft when cooked and is favoured by the elderly or others with poor teeth. Many of the other species, especially those of Southeast Asia and Madagascar, also have distinctive flavours and are highly regarded, as is the American *D. trifida* in the Caribbean.

Recently, there has been much interest in establishing mechanized production of some form of "instant yam," which could be reconstituted simply with water in a manner comparable with the "instant potato" popular in Europe and North America. The earliest experiments were undertaken in the Ivory Coast in the early 1960s and the product, known as Foutoupret, was alleged to be quite acceptable, although no commercial production developed. In the late 1960s and early 1970s, a factory was established in Nigeria producing a drum-dried flake, sold commercially for several years under the trade name Poundoyam. The reconstituted product fairly closely resembled fufu. The factory went out of production partly because of difficulties of supply of yams to its location near Lagos, remote from major yam-producing areas. At about the same time, a pilot plant, also using drum-drying, was established in Barbados, processing *D. alata*, the aim here being to yield a product resembling mashed potato more than West African fufu. Again, it functioned for several years, also making some sweet-potato flake but eventually closed over problems of supply of raw material. I understand that further attempts are under way in Nigeria to prepare a diced product that reconstitutes to a substance approximating fufu. I would be pleased to receive any information about the development of this new project, especially concerning its commercial success. Fuller details of the earlier attempts at processing yam for human food are given elsewhere (Coursey and Ferber 1979; Coursey 1983b).

Desirable though it may be to produce a convenience food from yam, particularly for modern urban society, the fact remains that there will always be a strong demand in both rural and urban areas for fresh yam. Extension of storage life of fresh yam tubers is still, therefore, a major priority. Apart from mechanical damage inflicted during or after harvesting, losses during storage under the traditional system are caused mainly by preharvest pathogens (Noon 1978), but the ultimate storage life is determined by the inherent dormancy and quality of the yam tuber itself; the length of dormancy is fundamentally important. Many trials have been undertaken with yams using the sprout inhibitors that are traditionally successful with potatoes and are widely used with that crop. All these experiments have been total or near-total failures. The reasons have recently been elucidated (Passam 1982a; Passam et al. 1982); in the yam, the bud primordia for regrowth at the end of dormancy are not formed at harvest as they are with potato, and there is, therefore, nothing on which a sprout suppressant can act. A small extension of dormancy can be achieved if a sprout suppressant is applied at the end of dormancy, and the traditional yam farmers' practice of removing sprouts manually from the tubers in the barn is believed also to contribute to delaying the breakage of dormancy. Both techniques, however, have only limited application and can delay breakage of dormancy by only a matter of weeks. Variable results have been obtained with gibberellins (Passam 1982a).

A possibility for the extension of the dormant life of yams to supply markets for longer periods is storage at reduced temperature. However, since my initial work (Coursey 1968a), several authors have found that cool storage presents many difficult practical problems at the commercial level. Yams are susceptible to chilling injury, and there is much variation even within a particular batch of a single cultivar in the exact temperature at which chilling injury occurs. With the majority, exposure to temperatures below 10°C, or even 14°C, for any substantial period will result in irreversible biochemical damage that makes the tubers totally unsuitable for human consumption within days of their being removed from cool storage (Adesuji 1982; Demeaux et al. 1982). Being convinced of the limited applicability of cool or cold storage for yams, Adesuji (1982) and Demeaux et al. (1982) independently studied the use of gamma irradiation as an alternative means of extending dormancy. Using gamma dosages of the order of 7.5 krad, they were able to keep the tubers in good condition for 6–8 months. Similar techniques have been used in developed countries for extending the storage life of potatoes.

The only application of yams for industrial

purposes is the manufacture (by a water-extraction and settling process) of starch from *D. hispida*, an Asiatic species similar to *D. dumetorum* and even more toxic. The total amount of yam devoted to this purpose is, however, quite small, and the industry exists only in the Philippines.

Certain members of the genus *Dioscorea* are sources of steroids for medicinal purposes, but they are totally different from the edible yams.

Sweet Potato

The sweet potato is rather anomalous. Originally a native of Mexico, it is the only economic species among the 300 or so within the genus *Ipomoea*. It has spread around the tropical and subtropical world in both directions, crossing the Pacific before European-contact times (Yen 1974). It is widely distributed but most (80%) of the world's production originates from China (Table 4). The crop is also quite important in Japan, in the neighbouring Ryukyu Islands, and in the southern states of the USA (Edmond 1971). Southeast Asia (Calkins 1979; Luh and Moomaw 1979; Villareal and Griggs 1982) and highland East Africa comprising Rwanda, Burundi, and Uganda account for a substantial proportion of the production in the tropical world. Throughout New Guinea and Melanesia in general, the sweet potato is becoming more and more important as a result of a lethal virus complex affecting the greatly preferred *Colocasia*. It is particularly important in the highland areas of New Guinea, where the climate is cool.

Throughout most of the tropics, sweet potato is consumed fresh after boiling, frying, or roasting. The majority of tropical peoples who consume it prefer white-fleshed, starchy cultivars to those that have been developed at considerable expense in the United States to have a high carotene (vitamin A) content. As with all crops, there is a great deal of variation in organoleptic preferences among ethnic groups, but the sweet cultivars from the USA with their fairly strong flavour are unacceptable to tropical populations, especially those who are accustomed to yam. In West Africa in particular, the sweet potato is likely to be popular only among some of the northern ethnic groups. West Africans of the forest and southern savanna would regard such a sweet commodity as being "un-African" and, therefore, suitable only perhaps for children.

Nevertheless, the majority of sweet potatoes produced in tropical countries are used as human food, boiled, fried, or roasted. In the South Pacific, sweet potatoes are often roasted in underground ovens in the same way as *Colocasia*.

The production potential of the crop is high because as many as four crops can be grown annually in some areas. Thus, sweet potato could be used as an animal feed in developing countries, as it is in the United States. Not only the roots but also the vines can be used, and whole-plant ensilage is a distinct possibility.

Much of what has been done in the southern states of the USA (Edmond 1971) is not applicable to the tropical world. American taste tends to run to the sweeter type of sweet potato, and a substantial portion of the crop grown there is canned in a sugar syrup. Nevertheless, the Caribbean populations in general have lost the traditional African preference for nonsweet foods, and the sweet potato is quite popular in many of

Table 4. Sweet-potato production and utilization in developing countries (FAO 1982a).

	Production		
	10^6 t	% of global total	kg/person
Total developing countries	143.7	98.5	43.1
China	125.7	87.4	124.7
Vietnam	2.4	1.6	43.7
Indonesia	2.1	1.4	13.8
India	1.5	1.0	2.1
Korean Republic	1.1	0.7	28.3
Rwanda	0.9	0.6	189.5
Burundi	0.9	0.6	213.4
Brazil	0.8	0.5	6.4
Bangladesh	0.8	0.5	8.8
Uganda	0.7	0.4	49.9

Table 5. Potato production and utilization in developing countries (FAO 1982a).

	Production	
	10^6 t	kg/person
Total developing countries[a]	50.7	15.2
China	15.0	14.9
India	9.6	13.8
Turkey	2.9	62.5
Argentina	2.2	82.1
Colombia	2.1	79.7
Brazil	1.9	15.3
Peru	1.6	89.8
Korean Republic	1.6	40.9
Egypt	1.1	26.0
Chile	1.0	89.2

[a]Developing-country production as % of global production = 19.7.

the islands, with appreciable quantities being exported to North America and to Britain (Bell and Coursey 1970) to provide for the immigrant communities of Caribbean origin living there.

One of the major problems of sweet potato in the tropics is its perishability. Grown under temperate conditions, the only major storage problem is protection from cold, as the sweet potato, like the yam, suffers from chilling injury at about 10°C. In the tropics, however, sweet potatoes are liable to preharvest attack by tuberboring insects (*Cylas* and *Eucepes*) and postharvest decay. As a result of the storage problems, the tropical sweet-potato crop is used shortly after harvest. In the Philippines, superior tubers are set aside for human use immediately after harvest, and the remainder are relegated to stock feed (Villanueva 1969). In highland New Guinea, where sweet potatoes are by far the most important staple, they are commonly cured by being hung up near a fire and, in some cases, even smoked. In New Guinea and other parts of Melanesia, they are commonly fed to pigs — a practice that could be regarded as a way of storing sweet potato in the form of pork consumed at festive occasions (Siki 1979).

Potato

Solanum potatoes are also something of an anomaly compared with other tropical root crops: although their origin is tropical — only a few degrees south of the equator in the Andean altiplano of Peru and Bolivia — their natural habitat is at such a high altitude that they have adapted very easily to the ecological conditions of the temperate countries and have developed there to a vastly greater degree than they have in the tropical world (Salaman 1949). Nevertheless, their production in the tropical world has increased greatly in recent years (Table 5) and has surpassed yam and sweet potato together, almost doubling in the last decade. Although much of this increase has been in the highland tropics — not only in the original home of the crop in South America but also in countries such as Kenya and India — extensive research has been undertaken and has led to enhanced production under conditions at lower altitudes, sometimes not far above sea level. Much of this work has been initiated or undertaken by the Centro Internacional de la Papa (CIP) in Peru, usually in collaboration with national research organizations (French 1972).

Although in the developed world the potato has many industrial and food-processing uses, including starch and alcohol (Smith 1977), potatoes in the developing countries are almost exclusively eaten fresh. Nevertheless, a change in food usage has taken place in many countries and has resulted in a rapid increase in potato production in the tropical world. As recently as 20 or 30 years ago, the potato was restricted to the highland tropics and, elsewhere, was confined to use by privileged economic groups, especially expatriates. Against this background, merchants could afford refrigerated storage, and producers could tolerate exceedingly low yields. This pattern still exists in some areas, but, in many countries, potato is becoming an everyday staple food of the producer. Kenya and highland India are of particular interest, as the potato is becoming quite widely accepted as a subsistence crop as well as a crop for sale at high prices for luxury markets.

To eliminate storage at artificially reduced temperatures, producers have adopted the philosophy of "storage avoidance": spreading production through as large a portion of the year as possible. Another approach currently being recommended by CIP is to store the tubers in the cool highland production areas and transport them to urban centres of demand, etc., which are frequently in the lowlands, as late as possible. For seed potatoes, storing the tubers in simple structures exposed to diffused light, which minimizes sprouting, shows great promise. A major storage problem is the potato tuber moth (Booth and Shaw 1981). In the Andes, potatoes are commonly stored in stacks incorporating layers of a local aromatic plant, "muña," the essential oil of which has a strong repellent effect

on the tuber moth. Aromatic herbs such as *Ocimum* in West Africa might have similar effects and contribute to the reduction of losses by potato tuber moth in potato storage.

In the potato's area of origin, for hundreds of years — long before European contact — local inhabitants have been processing the potato into a product known as chuño (Werge 1979). They slice the tubers, expose them to freezing temperatures at night to break down the cellular structure, press them at the same time as exposing them to the sun during the day. This process is only suitable for comparatively limited parts of the tropics where freezing temperatures occur at night.

Cocoyams and Other Aroids

The total production of the aroid root crops, of which *Colocasia* and *Xanthosoma* are by far the most important, is far less than that of yams and cassava or even potato and sweet potato. Nevertheless, they are important in that they are widely distributed. *Colocasia* is well adapted to cultivation under swamp or even flooded conditions, making the use of otherwise useless land possible. Other cultivars, especially of *Xanthosoma*, are adapted to drier upland conditions, although they generally yield less in terms of tonnes per hectare. Under good conditions, cultivars of both genera can be exceedingly high yielding (Coursey 1968b). They are now both of pantropic distribution, *Colocasia* having diffused in cultivation from its origin in Southeast Asia in ancient times and *Xanthosoma* recently moving to most of the areas where *Colocasia* is grown. Outside Hawaii, where the cultivation of *Colocasia* is highly organized, these crops are essentially backyard crops. Over the last few years, a trade in *Colocasia* (more than 2.0×10^3 t annually), has developed from Fiji, Tonga, and especially Samoa, to support Polynesian immigrants in New Zealand (Watson 1979). Similarly, substantial quantities (1.0×10^3 t annually), mainly dasheen — *C. esculenta* var. *esculenta* — are exported from the Caribbean to the United Kingdom where, again, they are used mainly by immigrants (Bell and Coursey 1970).

Harvested when required, cocoyams are seldom stored, and the small amount of information about their storage behaviour is conflicting. In Polynesia, *Colocasia* cultivars (known as taro or dalo) are sometimes fermented as a paste in pits in the ground, which it is claimed can be kept for several months; a similar technique is used for pulp made from breadfruit. I do not know the details of the process, which is said to be dying out with the introduction of imported foods. A study of the microbiology involved is desirable. In Africa and those parts of Asia where the crop is important, many varieties are known, and there are strong local preferences for one or another. In Africa in particular, *Xanthosoma* is tending to take over from *Colocasia*; the reason being given is that the former can yield a culinary product not too dissimilar from yam fufu. The fact that it is used quite widely as a shelter crop for young cocoa has contributed substantially to the spread of *Xanthosoma* in West Africa. The corms or cormels are usually eaten boiled, mashed, or sometimes pounded, frequently mixed with other staples, such as yam or plantain. They are grated and incorporated into soups or stews. The leaves of several cultivars are consumed, especially in the Caribbean and Latin America, as constituents of either soups or salads. One species, *X. brasiliense*, is grown entirely for its leaves for salad use rather than for its starchy corms.

No discussion of the use of the aroids as food — virtually their only use — would be complete without mention of their irritancy or "scratchiness." Although they vary in this quality, many cultivars have such a high degree of irritancy as to be unpalatable unless thoroughly cooked. Some individuals, however, are able to consume more irritant cultivars than are others. Many animals are also sensitive to the irritant. Most studies (Coursey 1968b) have attributed the quality to the presence of needle-shaped crystals or raphides of calcium oxalate, which can be detected microscopically in the tissues of the plant. Without doubt, these contribute to the effect, but recent research suggests that, in common with several other aroids, the cells that contain the raphides contain a toxic substance that irritates the wounds caused by the raphides. The enormous variation between cultivars suggests that breeding programs could eliminate or minimize the problem.

Some cocoyam corms, cormels, and leaves are fed to household stock, such as goats, in many parts of the tropics, but no organized industry has been built for animal feeds. The whole plant might well prove suitable for ensilage as animal feed (Coursey and Halliday 1975), and some experimentation, mainly with *Colocasia*, has been undertaken in Hawaii (Steinke et al. 1982; Wang and Nagarajan 1983). The work was initially conducted with the leaves, which are often wasted in Polynesian agricultural systems, but some ex-

periments on whole-plant ensilage were also conducted. Both types of silage proved entirely acceptable to pigs and ruminants. In view of the high yields that can be obtained with certain aroid cultivars, this source of animal feed appears well worth investigating in other tropical countries.

Colocasia starch grains are exceedingly small (Rasper 1981) so they may be suitable for the manufacture of biodegradable plastics, in which the size of starch particles is directly related to speed of biological degradation (Griffin 1979).

The remaining aroid genera, *Alocasia, Cyrtosperma, Amorphophallus*, and *Anchomanes*, are used only as local foods in their area of production. An exception outside the developing world is that of *Amorphophallus rivieri*, which stores its carbohydrate reserves as mannans instead of starch and is utilized in Japan for commercial production of mannans and mannose. If the tropical species also store their carbohydrate in this form, industrial utilization of these crops, which are particularly important in south India and in Indonesia, should be possible.

Further information on aroid utilization has been published elsewhere (Plucknett 1979; IFS 1982), and a multiauthor monograph on *Colocasia*, edited by Wang, has just been released.

Conclusions

As far as can reasonably be predicted, the major tropical root crops will continue for several decades to occupy essentially the same position in agricultural economies as they do today; they will primarily remain a source of human food. Use of the cheaper root crops, such as cassava and sweet potato, as animal feed will probably increase, although the opportunities for export of dried products show little capacity for improvement and may even decline. The decline will probably be more than counterbalanced by increased use, especially of cassava, in producer countries. The use of silage from aroids for animal feed may also have a future.

Industrial utilization, mainly for starch, may increase, especially in countries where there is a local demand, but the position of cassava starch on international markets is not strong. Specialty uses for some root-crop starches are a possibility.

The use of cassava or sweet potato for fermentation of industrial alcohol is not likely to increase unless petroleum costs rise substantially.

In the long term, mechanized production of "instant" reconstitutable products will be established at the industrial level, especially for yam.

CASSAVA

GENETIC PARAMETERS OF CASSAVA

N.M. MAHUNGU,[1] H.R. CHHEDA,[2] S.K. HAHN,[3] AND C.A FATOKUN[2]

We investigated six diverse cassava populations grown during 1979–80 and 1980–81 at the International Institute of Tropical Agriculture (IITA), Ibadan, to estimate genetic parameters for 22 traits of cassava. The data, when analyzed, revealed that: considerable variation existed both within and between the populations for most of the characters; the coefficients of variation for phenotype and genotype were largest for root yield (85% and 62%, respectively), quite large for the roots per plant and root size (60% and 40%), moderate for harvest index and total number of branches (45% and 30%, respectively), and low (less than 30% and 15%) for stem girth, canopy width, and plant height at harvest. Heritability estimates as well as expected genetic gain also varied considerably. On average, root yield and number of roots showed moderately high heritability (50%) and high expected response to selection (88% and 64%, respectively). Relatively high heritability values were obtained for harvest index (49%) and dry-matter content (52%), but they were associated with expected genetic gains of only 50% and 29%, respectively. Agronomic traits such as stem girth, canopy width, and plant height at harvest showed moderate-to-low heritability values (32–42%) associated with low expected genetic advance (15–18%).

Cassava breeding programs have been primarily based on selection for yield and have not included physiological or morphological characters in selection procedures. It would, therefore, be useful to have a quantitative statement of the relative importance of heredity and environment in determining the expression of characters.

In asexually reproduced plants, like cassava, any combination of genetic factors that yields a superior genotype can be used through clonal propagation. In such circumstances, all genetic variability can be used and heritability estimates have meaning (Hanson 1963).

This study was initiated to estimate certain genetic parameters of various cassava traits. Heritability is in most cases taken as a valid statistic for describing the relative variability inherent in a character and must represent a practical concept to have utility in plant breeding. The expected response to selection under a particular selection scheme supplies the practical information the breeder desires, and heritability estimates provide important information regarding advances that may be expected from selection. High heritability indicates that selection of desirable genotypes on the basis of phenotypic performance is likely to be effective.

MATERIALS AND METHODS

We conducted two separate field studies using different cassava populations at the International Institute of Tropical Agriculture (IITA), Ibadan. One, conducted during the 1979 growing cycle, utilized two genetically broad-based composites — A from African sources and B from Latin America and India, 45 and 42 genotypes, respectively. The other study conducted during the 1980 growing cycle, utilized mature cuttings of seedlings from four segregating F_1 families produced from crosses between Isunikankiyan × 58308 (35 offspring), TMS 30395 × Isunikankiyan (35 offspring), 58308 × 60506 (25 offspring), and 60506 × TMS 30395 (20 offspring). Both studies were harvested at 12 months; the experimental design was a randomized complete block, with four replications. In each replication, for each genotype, four stem cuttings were planted in single rows, 1 m × 1 m. Observations were made on 22 traits.

Coefficients of variation (CV — %) were com-

[1] Programme national manioc (PRONAM), Kinshasa, Zaire.

[2] Department of Agronomy, University of Ibadan, Ibadan, Nigeria.

[3] International Institute of Tropical Agriculture, Ibadan, Nigeria.

Table 1. Phenotypic (PCV) and genotypic (GCV) coefficients (%) of variation of characters of six cassava populations.

Character	A		B		Families from Isun. × 58308		30395 × Isun.		58308 × 60506		60506 × 30395		Mean	
	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV
Root yield	115.92	88.50	119.27	83.19	65.67	45.63	52.31	36.08	103.19	87.40	50.44	30.17	84.48	61.83
Roots/stand	98.46	72.17	99.90	68.99	43.44	26.04	34.46	21.66	48.84	43.66	34.30	24.11	59.90	42.77
Root size	88.24	29.41	77.11	48.77	61.49	27.50	41.67	26.35	74.43	52.63	40.00	40.00	63.82	37.44
Harvest index	64.28	45.46	78.57	55.56	35.71	22.59	37.04	23.42	40.00	40.00	35.71	15.97	48.55	33.83
Dry matter, roots	13.16	8.22	15.84	10.94	11.80	9.50	10.27	7.18	11.77	8.45	12.29	9.57	12.52	8.98
Starch	22.85	13.16	25.11	14.13	33.88	24.56	30.91	18.75	21.96	15.78	19.02	10.67	25.62	16.18
HCN														
Roots	40.02	33.79	34.99	22.87	38.41	21.25	38.57	12.78	39.21	22.96	57.88	24.30	41.51	22.99
Leaves	28.90	15.97	27.46	16.98	17.81	10.47	22.12	11.95	20.25	12.33	24.76	12.00	23.55	13.28
Nodes/stand	33.07	24.55	38.80	31.60	39.15	31.20	33.92	26.51	37.24	31.59	31.67	24.31	35.64	28.29
Branching height	34.35	26.85	46.85	39.53	43.20	32.98	41.84	33.09	47.42	39.61	38.40	27.36	42.01	33.24
Flowering														
Age	21.64	12.49	30.13	24.84	19.56	16.76	18.63	12.73	30.72	28.63	22.06	18.93	23.79	19.06
Height	33.09	22.68	39.55	31.13	35.40	29.99	37.04	29.82	44.76	40.90	32.43	27.46	37.05	30.33
Resistance														
CMD	34.88	24.78	32.26	22.81	20.64	14.69	23.64	18.78	30.72	22.76	17.56	13.00	26.62	19.47
CBB	35.47	18.02	35.05	21.70	29.51	10.43	26.77	5.47	35.58	20.86	30.04	10.01	32.07	14.42
Angle of forked branches														
1st	16.52	8.47	11.82	8.16	15.07	10.05	12.35	9.45	13.63	7.50	11.00	6.85	13.40	8.41
2nd	13.66	8.03	11.17	6.75	11.94	7.62	14.59	9.28	14.06	8.35	9.93	7.32	12.56	7.90
Stem girth	26.80	14.00	21.28	13.13	18.96	11.49	12.04	6.16	16.07	12.07	15.22	12.20	18.40	11.58
Height at harvest	26.46	16.43	18.98	12.03	17.97	11.67	11.52	6.71	21.83	16.36	11.84	3.65	18.10	11.14
Canopy width	35.09	17.92	33.08	13.73	27.73	17.45	22.44	11.98	26.96	13.66	23.17	17.31	28.08	15.34
1st forked branches/stand	20.58	9.60	20.24	9.44	19.68	11.36	20.08	4.10	21.07	7.15	24.49	14.72	21.02	9.40
Branches/stand	49.95	32.70	38.60	24.40	45.59	26.11	31.04	19.93	57.87	49.23	39.91	18.45	43.83	28.47
Stems/stand	39.93	17.86	47.11	23.11	34.40	19.39	37.83	25.66	33.16	21.98	28.00	19.34	36.74	21.22

Table 2. Broad-sense heritability (h^2) in % and expected response to selection (R) (% of mean and i = 5%) of cassava traits in six cassava populations.

					Families from									
	A		B		Isun. × 58308		30395 × Isun.		58308 × 60506		60506 × 30395		Average	
Character	h^2	R	h^2	R	h^2	R	h^2	R	h^2	R	h^2	R	h^2	R
Root yield	44.63	106.56	47.78	117.65	48.06	65.24	47.47	51.03	71.79	152.80	35.66	37.20	49.23	88.41
Roots/plant	53.80	109.03	47.66	98.37	35.95	32.22	39.43	28.04	79.86	80.32	48.48	34.59	50.86	63.76
Root size	14.44	26.47	38.15	62.07	24.14	30.44	40.00	41.67	57.14	89.47	38.46	32.00	35.39	47.02
Harvest index	41.44	54.88	54.38	88.01	44.49	32.70	50.00	38.15	75.00	61.80	28.75	21.15	49.00	49.45
Dry matter, roots	38.99	105.68	47.71	15.56	64.81	15.76	48.93	10.35	51.52	12.50	60.72	15.38	52.11	29.21
Starch	33.20	17.00	32.46	15.90	52.57	24.43	37.30	14.70	48.97	15.78	31.47	12.33	39.33	16.69
HCN														
Roots	71.26	58.75	42.74	30.80	30.62	24.23	10.97	8.72	34.27	27.68	17.63	21.02	34.58	28.53
Leaves	30.53	18.17	38.27	21.65	34.60	12.69	29.15	13.29	37.06	15.46	23.47	11.97	32.18	15.54
Nodes/plant	55.12	37.55	66.31	53.00	63.50	51.21	61.06	42.67	71.97	55.20	58.92	38.44	62.81	46.35
Branching height	61.10	43.24	71.22	68.73	58.29	51.87	62.53	53.90	69.77	68.16	50.78	40.17	62.28	54.35
Flowering														
Age	33.32	13.35	67.98	36.92	73.35	37.49	46.67	20.78	86.89	47.62	73.66	34.56	63.63	31.79
Height	46.96	32.01	61.98	50.49	71.75	52.33	64.82	49.46	83.49	76.98	71.72	47.91	66.79	51.53
Resistance														
CMD	50.70	36.43	49.52	32.91	50.27	21.37	62.79	30.58	54.91	36.94	53.79	19.46	53.66	29.62
CBB	25.34	18.52	38.21	27.59	10.21	6.21	2.89	15.94	33.03	24.21	11.85	7.33	20.66	16.63
Angle of forked branches														
1st	26.29	8.95	47.67	11.60	44.44	13.80	58.60	14.90	30.24	8.49	38.76	8.78	41.00	11.09
2nd	34.57	9.73	36.50	8.40	40.74	10.02	40.91	12.23	35.30	10.22	55.08	11.27	40.52	10.31
Stem girth	27.30	15.07	40.46	17.74	36.72	14.24	26.35	6.54	56.12	18.58	63.93	20.06	41.81	15.38
Height	38.54	21.01	40.15	15.70	42.20	15.62	33.90	8.05	56.18	25.26	9.52	23.22	36.75	18.14
Canopy width	26.08	18.85	17.24	11.75	39.61	22.63	28.50	13.17	25.67	14.26	55.80	26.63	32.15	17.32
1st forked branches/stand	20.30	8.61	19.26	8.03	32.92	13.34	5.74	2.37	12.09	5.25	35.44	17.88	20.96	9.25
Branches/stand	42.84	44.08	39.95	31.77	32.79	30.79	41.22	26.36	72.36	86.27	21.37	17.57	41.76	39.47
Stems/stand	19.47	16.02	23.27	21.58	32.08	22.73	46.15	35.96	44.13	30.14	10.96	6.32	29.34	22.29

puted as suggested by Burton (1952): $100\sigma/\bar{X}$ where σ is the standard deviation and $\bar{X}$ is the mean of the trait. Broad-sense heritability (h^2) was estimated as $h^2 = \sigma^2g/\sigma^2p$ where σ^2g is the genotypic variance and σ^2p is the phenotypic variance (Allard 1960). Response to selection (R) was predicted as $ih^2\sigma p$ where i is the standardized selection differential at 5%, h^2 is the heritability, and σp is the phenotypic standard deviation.

Results and Discussion

Among the various characters studied (Tables 1 and 2), root yield, on average, had the largest phenotypic and genotypic CV (85% and 62% respectively); dry matter in roots and angle of second forking branches had the least phenotypic (about 13%) and genotypic (9% and 8% respectively) CV. Although phenotypic CV for root size (64%) was somewhat higher than that for number of roots (60%), the opposite was true for genotypic CV. The phenotypic and genotypic values were smaller for stem girth (18% and 12% respectively); plant height at harvest (18% and 11% respectively); and canopy width (28% and 15% respectively).

Heritability and genetic advance for the different characters studied varied considerably (Table 2). Moderately high heritability associated with high genetic advance was observed for root yield, number of roots/plant, and branching height in most of the populations. Aggarwal and Kang (1976) observed high genetic gain associated with high heritability values for some characters in horse gram and postulated additive gene control for these characters. Additive genes are probably also operating in cassava for such traits, and, consequently, direct selection, applied on the traits, can be expected to produce worthwhile results.

Moderate-to-high heritability in characters such as plant height at flowering, number of days to flowering, harvest index, resistance to cassava mosaic disease, and dry matter in roots was associated with relatively lower genetic gain, indicating a somewhat limited scope for further improvement by selection. The low expected genetic gain for these characters, despite their high heritability, mainly reflected their low genotypic CV. Some characters such as stem girth, plant height at harvest, and canopy width had low heritability values associated with low expected genetic gain. A large proportion of the variability observed in these traits was caused by environment.

Root size showed fairly low heritability (35%), with a sizable expected genetic gain of 47%, indicating the possibility of significant progress in improvement through selection and supporting the findings from another study at IITA in which heritability for root size was estimated to be 37% (IITA 1975).

The additive portion of the genotypic variance for some of the characters may be small, but this possibility is not important if selection is being done on clonal material because the nonadditive portion can be fixed vegetatively (Hanson 1963). As genetic advance in cassava is measured by the potential of clonal types, estimation of heritability as in this study could be quite useful for plant-breeding programs.

EVALUATION OF CASSAVA CLONES FOR LEAF PRODUCTION IN ZAIRE

N.B. LUTALADIO[1]

At Mvuazi, Zaire, the tops of 30 cassava clones were harvested periodically, and the production of tender leaves for use as a vegetable was evaluated. The local variety, Mpelolongi, had the highest yield (10.2 t/ha) of tasty leaves, but several other varieties proved to be good leaf producers. Staff at Programme national manioc (PRONAM) are studying ways of improving varieties for higher yields of both leaves and roots. Cultural practices and factors influencing leaf production will be analyzed.

In Zaire, cassava leaves are eaten as a vegetable (mpondu, saka-saka) and are an important source of protein, vitamins, and minerals. Similarly, they form a substantial supplement in Congo, Cameroon, Guinea, Sierra Leone, etc. where for some time they have been part of the regular diet.

Whereas the roots contain only 1–2% protein, cassava leaves contain up to 7% protein/fresh weight and close to 20–40% protein/dry weight (Leung et al. 1972). Chemical composition varies with cultivar and ecophysiological conditions, but annual yield of protein from the leaves (7–20 t/ha) could be as high as 1400 kg/ha (Thampan 1980).

Despite low levels of methionine, the leaves have a richer amino-acid content than the roots (Terra 1964). With a digestibility of 70–80%, the leaves have a normal biological value ranging from 44% to 57% and as high as 80% with methionine supplements (Thampan 1980).

Studies have been initiated by PRONAM to evaluate the leaf production of several clones and to promote the distribution of the best clones in areas where the demand for cassava leaves is great.

MATERIALS AND METHODS

The evaluation comprised 30 cassava clones, including 13 from INERA's (Institut national d'études et de recherches agronomiques) collection, 16 that were maintained or developed by PRONAM, and 1 local clone that is widely grown. The clones were planted at Mvuazi, Zaire, in alluvial soil during 1980–81.

Twelve plants/variety were planted in rows for each parameter and each replication. Spacing within and between rows was 1 m × 1 m. The experimental design was randomized complete blocks, with 3 replications.

Leaves were harvested 4 months after planting and every 2 months until 8 months. About 25 cm were removed from the stem top bearing several young leaves that had matured but were still tender enough to be consumed as a vegetable.

The stem tips were grouped in bunches by clone and weighed; then, the young leaves were counted and separated from the petioles and stems, each component being weighed separately. Leaf colour and flowering of the clones were also recorded, as some consumers prefer leaves from flowerless stem tops.

The hydrocyanic-acid content of the leaves was determined by means of the sodium picrate test (Sadik et al. 1974), and, on the basis of test results, the clones were divided into groups with high, average, and low HCN levels.

Taste was evaluated. The top buds and leaves, after being separated from the petioles and stems, were:

- Cleaned in lukewarm water;
- Either placed on a hotplate or immersed in hot water (ca 80°C);
- Pressed between the hands to remove excess water;
- Transferred to a mortar or standard grinder;
- Pounded or ground according to traditional methods;

[1] Programme national manioc (PRONAM), Mvuazi, Zaire.

- Mixed with onion and hot peppers;
- Placed in a pot of water;
- Boiled until free of the pungent odour;
- Seasoned with palm or moambe oil and salt and mixed with fish or meat (optional); and
- Simmered until cooked.

Results

The number of tender leaves for human consumption ranged from 6.2 to 19.8 depending on the clone. Clones 93/1, Mpelolongi, 02864, coll. 24, and coll. 154 produced more tender tips and a significantly greater number of soft leaves, i.e., 19.8, 15.4, 14.9, 14.2, and 14.0 leaves/plant, than the other clones (Fig. 1).

The bunch weight per plant for six clones, i.e., Mpelolongi, 02864, coll. 108, 260/11, coll. 180, and 429/7 was 18.5, 16.5, 14.6, 13.8, 13.6, and 13.2 t/ha, significantly higher than that of other clones. Clones 93/1, B-136, C-11, and coll. 146 gave poor yields, i.e., 3.2, 3.7, 2.2, and 2.5 t/ha, respectively.

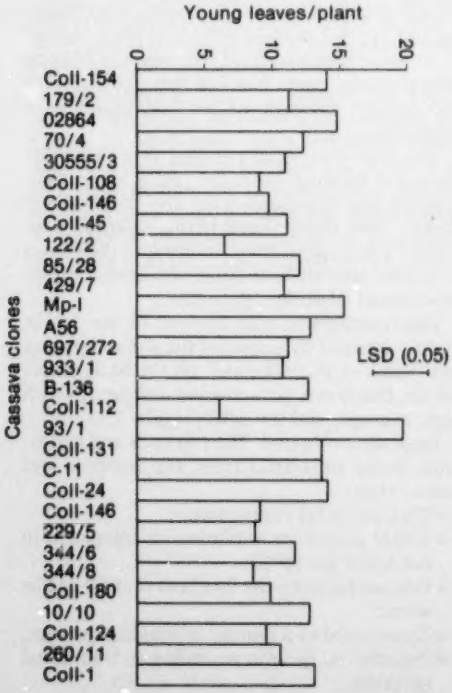


Fig. 1. *Young leaves produced by 30 cassava clones at Mvuazi, Zaire.*

Table 1. Leaf yields of 30 cassava clones at Mvuazi, Zaire.

	Fresh yield (t/ha)		Leaf weight/ bunch weight(%)
	Stem tops	Edible young leaves	
Coll. 154	5.3	1.8	33.9
179/2	5.7	2.8	49.1
02864	16.5	8.2	49.7
70/4	10.7	5.7	53.3
555/3	12.7	7.1	55.9
Coll.108	14.6	6.6	45.2
Coll.146	10.0	3.9	39.0
Coll.45	4.2	2.5	59.5
122/2	4.6	2.6	56.5
85/28	4.6	2.2	47.8
429/7	13.2	8.4	63.6
Mp-L.	18.5	10.2	55.2
A56	10.9	6.1	55.9
697/279	4.1	2.2	53.6
933/1	5.2	2.9	55.8
B-136	3.7	2.2	59.5
Coll.112	10.9	5.6	51.4
93/1	3.2	1.9	59.4
Coll.131	4.6	2.5	54.4
C-11	2.2	1.2	54.5
Coll.24	6.3	3.9	61.9
Coll.146	2.5	1.2	48.0
229/5	4.5	1.9	42.2
344/6	12.9	7.7	59.6
344/8	10.5	4.4	41.9
Coll.180	13.6	6.5	47.8
10/10	12.3	6.6	53.6
Coll.124	6.1	3.3	54.1
260/11	13.8	8.2	59.4
Coll.1	6.6	4.2	63.6
$\bar{X}$	8.5	4.5	52.8
LSD (0.05)	7.3	4.1	11.4

Similarly, the leaves, after separation from the stem tops, of Mpelolongi (10.2 t/ha), 429/7 (8.4 t/ha), 02864 (8.2 t/ha), 260/11 (8.2 t/ha), 344/6 (7.6 t/ha), and 555/3 (7.1 t/ha) weighed significantly more than those for the other clones. As a percentage of stem tops, leaf weight for clones 429/7, coll. 1, and coll. 24 was greater than 60 (Table 1).

Leaves ranged from light to dark green or yellowish green with shades of green or brown in the top bud. Some clones produced flowers 4 months after planting. This was true for most of the improved clones, such as 70/4, 85/28, 429/7, A56, 697/272, 933/1, 93/1, 229/5, 10/10, and

Table 2. Characteristics and quality of young leaves from 30 clones, Mvuazi, Zaire.[a]

Clone	Flowering	HCN content	CMD score	Taste after cooking
Coll. 154	+	Avg	3.5	Very good
179/2	–	High	2.5	Good
02864	+	Avg	3.5	Good
70/4	+	Low	3.5	Very good
555/3	–	Low	2.5	Good
Coll. 108	–	Avg	3.0	Good
Coll. 146	–	Avg	3.5	Good
Coll. 45	–	Avg	3.5	Good
122/2	–	High	3.0	Good
85/28	+	Avg	2.5	Very good
429/7	+	Avg	3.0	Good
Mp-L.	–	High	3.5	Very good
A56	+	High	3.0	Good
697/279	+	Avg	2.5	Good
933/1	+	Avg	3.5	Good
B-136	+	Avg	3.0	Good
Coll. 112	–	Avg	3.5	Very good
93/1	+	High	2.5	Bitter
Coll. 131	+	Avg	3.0	Good
C-11	–	Avg	3.0	Good
Coll. 24	–	High	3.0	Very good
Coll. 146	+	Avg	3.5	Good
229/5	+	Avg	3.0	Good
344/6	–	Avg	3.0	Good
344/8	–	High	3.0	Bitter
Coll. 180	–	High	3.5	Good
10/10	+	Avg	2.5	Good
Coll. 124	–	Avg	3.0	Good
260/11	+	Avg	2.5	Good
Coll. 1	–	Low	3.0	Good

[a]Scoring at the time of the first harvest.

260/11. The local clone Mpelolongi and clones from the INERA collection either barely flowered or flowered late (Table 2).

High levels of hydrocyanic acid were found in the young leaves of clones A56, 122/2, Mpelolongi, 179/2, coll. 180, coll. 24, 93/1, and 344/8, whereas, in most of the clones, average levels were recorded. All of the clones contained some HCN, although low levels were noted in clones 70/4, coll. 1, and 555/3. These clones will eventually be subjected to quantitative analysis for HCN content.

In most of the clones, harvesting the leaves resulted in the emergence of cassava mosaic. In the INERA clones that had not been improved, the disease was slightly more severe than in the other clones (Table 2).

Mpelolongi, coll. 154, 70/4, coll. 112, 85/28, and coll. 24 rated highest in taste evaluation. Except for clones 93/1 and 344/8, which received poor ratings, all the clones were considered good (Table 2).

Discussion and Conclusions

In Zaire, young leaves of cassava plants can be harvested at intervals of 2 months, beginning 4 months after planting, without a marked decrease in root yield. Ideal clones rapidly produce leaves from planting until root bulking and maintain optimal leaf area for a long time. In other words, leaf production depends on the ability of the clone to produce new secondary or tertiary shoots.

Results from PRONAM suggest that Mpelolongi, 02864, and others such as 429/7 and 260/11 produce high yields of leaves, with an acceptable proportion of edible leaves to stems. Within the same clone, the proportion varies considerably, depending on the stage of development of the stake and the ecology of the culture site.

Leaf colour is a subjective characteristic in the appraisal of leaf quality, as preferences differ from area to area and individual to individual.

However, homemakers in Zaire report that more oil is needed for cooking the light green leaves than for dark green leaves.

When the top bud bears flowers that are mixed with the cassava leaves during cooking, the result is a bitter-tasting dish. This is the reason that a better quality vegetable is produced by nonflowering clones or clones that flower little or late.

A large percentage of hydrocyanic acid is eliminated by traditional methods of preparing the leaves as a vegetable, and HCN toxicity occurs rarely and only when cassava consumption is associated with inadequate nutrition. For example, in Ubangi (equator region) and Idjwi Island in the Kivu region (Delange and Ermans 1971; Delange et al. 1973), goitre and cretinism are endemic because of the combined effects of high cassava consumption and low iodine intake.

CASSAVA SCREENING IN RWANDA

J. MULINDANGABO[1]

In Rwanda, work to improve cassava was begun in earnest in 1979 following serious damage from diseases and pests, especially cassava mosaic, bacterial blight, and the cassava green mite. The purpose of this paper is to describe progress in research by the Institut des sciences agronomiques du Rwanda (ISAR) in conjunction with the International Institute of Tropical Agriculture (IITA) to obtain and screen breeding material for resistance to disease and the green mite. The future prospects of cassava research in Rwanda are also discussed.

In 1978, ISAR outlined a screening program to find productive, disease-resistant varieties of cassava. It has now begun advanced yield trials, and final results are expected in another year and a half. Initial findings are promising.

OBJECTIVES

The aim of cassava screening in Rwanda is to obtain varieties that are:

- High yielders in terms of quantity and quality per unit area and time;
- Resistant to disease and insects that have an economic impact, with efforts being concentrated on cassava mosaic, bacterial blight, and acariasis;
- Low in hydrocyanic acid;
- Adapted to different environments in the cassava-growing areas of Rwanda, nutritious, and likely to be accepted by consumers.

IITA's procedures (Hahn 1982) were adopted for cassava screening in ISAR but were adapted to the agroecological conditions found in Rwanda.

RESULTS

Since 1979, five series of seed beds were prepared, representing 42 794 seeds, of which 18 000 came from exotic varieties (IITA) and 24 794 from local families.

Natural infection by cassava mosaic caused little damage, and *Cercospora* had no economic impact, as it attacked only the lower leaves. Bacterial blight was not observed. None of the plants were spared infestation by the cassava green mite, although some of the clones exhibited tolerance, which was exploited in later screening. The root characteristics of each plant were recorded at harvest.

Clonal evaluation trials were conducted to check and substantiate nursery findings and to try to assess the material for yield. Four series of evaluation trials have already been conducted with roughly 300 clones planted in rows with 4–6 stakes/clone, depending on the availability of planting material.

Observations were regularly recorded; the findings were that:

- 8–10 clones developed mosaic, with the borders consisting of heavily infected plants to facilitate natural infection. The vector, *Bemisia tabaci*, seems to play a very minor role in transmitting the disease under the conditions existing at Karama.
- All the clones were attacked by *Cercospora henningsi*, but the upper leaves were spared. *Cercospora caribbaea* was less severe in its attack.
- The number-one enemy was the green mite, to which all the clones were susceptible, especially during the dry season. Consideration was given to importing plant material in the form of tissues from resistant varieties that have been identified by IITA.

Clones with yields greater than 20 t/ha were selected for a screening trial (Table 1) on the basis of response to diseases and pests and root

[1] Institut des sciences agronomiques du Rwanda (ISAR), Karama, Kigali, Rwanda.

Table 1. Results of clonal evaluation trials, 1980–82.

	1980	1981	1982
Planted	335	386	324
Infected with			
Mosaic	41	5	3
Cercospora	260	210	105
Acariasis	335	366	324
Eliminated	232	322	260

Table 2. Yields for the 10 best clones in the screening trial, 10 months after planting.

Variety	Fresh root yields (t/ha)	% of control yield	Origin
Kibombwe/1	31.3	210	Local
30572-1977/12	30.0	201	IITA
Eala 07/4	29.6	199	Local
AYT Bulk 1977/12	28.3	190	IITA
Ikiela/2	28.2	189	Local
IYT Bulk 1977/11	27.8	187	IITA
AYT Bulk 1977/11	27.1	182	IITA
PYT Bulk 1977/69	27.0	181	IITA
PYT Bulk 1977/29	26.5	178	IITA
IYT Bulk 1977/18	25.2	169	IITA
Eala 07 (control)	14.9	100	Average for 35 plots

characteristics. Screening tests were to compare varieties from the clonal evaluation with a local variety (control). Two screening trials have already been conducted at Karama, and a third is under way. Only the first, set up in 1981, has been completely analyzed. It included 103 clones from the 1980 clonal evaluation. The control Eala 07 included four clones.

During the trial, the harvest was staggered. The first harvest, at 10 months, allowed ISAR staff to detect early, productive species, and the later harvests ensured productive species with longer growing cycles were detected.

Findings showed clonal tolerance to mosaic, susceptibility to *Cercospora*-induced diseases and acariasis, and a wide genetic range in resistance to drought and attack by the cassava green mite.

At the first harvest, 44 clones were selected and planted in advanced yield trials at Karama, Rubona, Mututu, and Mutara. The yield for these clones was equal to or greater than 20 t/ha (Table 2). The second harvest took place exactly 15 months after planting. The 44 clones selected during the first harvest for the advanced yield trials continued to produce satisfactorily.

Root characteristics were far more interesting in the second than in the first harvest, and there was a substantial increase in yields (Table 3). In fact:

- Some yields had doubled; for example, the control — a late variety — increased from 14.9 t/ha at 10 months to 36.8 t/ha at 15 months; and
- Varieties Eala 07/4, Ikiela/2, PYT Bulk 1977/69 were among the 10 best in both harvests.

In the third harvest after 20 months (Table 4):

- The variety PYT Bulk 1977/31 doubled its 15-month (35.9 t/ha) yield; i.e., it produced 70.9 t/ha;
- Eala 07/4 and Ikiela/2 produced the same yields after 10 months as after 15 or 20 months;
- The local varieties produced higher yields after 20 months than did the exotic families, once again demonstrating that local varieties are late in maturing.
- In the control Eala 07, there was little difference between 15-month and 20-month yields; and
- Although 20-month yields were higher than 15-month yields, the increases did not offset the additional time that the crop occupied the land. The 15-month crop seems the best suited to conditions in Rwanda.

The 44 varieties selected after the first harvest were further tested in advanced yield trials at Karama, Rubona, Mututu, and Mutara. Five local varieties served as controls, bringing the

Table 3. Yields for the 10 best clones in the screening trial, 15 months after planting.

Variety	Fresh root yields (t/ha)	% of control yield	Origin
Kiryumukwe/1	59.3	161	Local
Ikiela/2	56.7	154	Local
PYT Bulk 1977/19	56.6	153	IITA
Eala 07/4	54.7	148	Local
PYT Bulk 1977/18	48.1	130	IITA
30001/9	47.3	128	IITA
PYT Bulk 1977/69	44.1	119	IITA
30595 Bulk 1977/10	40.5	110	IITA
30572 Bulk 1977/2	37.7	102	IITA
PYT Bulk 1977/31	35.9	97	IITA
Eala 07 (control)	36.8	100	Average for 35 plots

Table 4. Yields for the 10 best clones in the screening trial, 20 months after planting.

Variety	Fresh root yields (t/ha)	% of control yield	Origin
PYT 1977/31	70.9	172	IITA
Eala 07/4	68.7	167	Local
Kibombwe/14	64.7	157	Local
Ruharwe/3	57.4	140	Local
Ikiela/2	57.3	139	Local
Kiryumukwe/1	52.6	128	Local
Kiryumukwe/3	50.7	123	Local
PYT Bulk 1977/20	48.9	119	IITA
30395 Bulk 1977/9	48.2	117	IITA
IYT Bulk 1976/3	47.6	116	IITA
Eala 07 (control)	41.0	100	Average for 35 plots

total number of varieties included in the trials to 49.

The trials were conducted jointly with the Service des semences sélectionnées of the Mutara Office de valorisation agricole et pastorale du Mutara. In the four sites, each variety was planted in rows with 8 plants/row in a Fischer block design with four replications. Planting took place in October–November 1981. The varieties showed good growth except at Rubona where the land set aside for the trial was poor. In general, phytosanitary conditions were satisfactory in the four trials, indicating that screening had paid off. The crops were harvested in February and March 1983, i.e., after 15 months' growth (Table 5).

The variety Creolinha Java, which was introduced into Rwanda about 1930–32, stood out. Unfortunately, it tends to be fibrous and has not been accepted by the rural population. As it proved to be a good producer at all four sites, further work should be done on this variety.

A multiple mean comparison ($P < 0.05$) showed that Creolinha, Ntolili Seed 16, Kiryumukwe/3, Kibombwe/13, and Kiryumukwe/18 were significantly better than the other varieties; Kibombwe/13 was adapted to all four sites. Amer Eala 07, which currently has a wide distribution, proved to be a very promising variety. There are plans to improve it by crossing it with new varieties to shorten the growing cycle and introduce disease resistance. The differences attributable to environment were highly significant. The most favourable environmental conditions were found at Mututu and Mutara and the least at Rubona.

For a comparative varietal trial conducted at Karama, Rubona, and Mutara, 10 sweet varieties — Mulundi, Maguruyinkware, IYT Bulk 1977/11, PYT Bulk 1977/29, PYT Bulk 1977/66, Kiryumukwe/21, Kibombwe/13, Kiryumukwe/3, IYT Bulk 1977/17, and Kibombwe/14 — and 10 bitter varieties — Eala 07, Creolinha, Ntolili Seed 16, PYT Bulk 1977/69, PYT Bulk 1977/19, Kiryumukwe/18, 30395 1977/11, Maguruyinkware/1, Eala 07/4, Amer 6 months Seed 2/3 —

Table 5. Mean yields (t/ha) of 20 varieties in advanced yield trials.

Variety	Karama	Rubona	Mutara	Mututu	Mean
Creolinha	38.8	16.8	82.4	52.5	47.6
Ntolili seed 16	37.0	16.2	46.5	57.2	39.2
Kiryumukwe/3	26.7	17.7	62.0	45.9	38.1
Kibombwe/13	24.2	22.1	63.9	37.8	37.0
Kiryumukwe/18	24.5	19.4	60.4	33.8	34.5
IYT 1977/7	24.9	13.4	52.4	40.0	33.4
Kibombwe/14	29.6	16.6	61.5	24.1	32.9
Eala 07	37.8	19.3	39.9	34.4	32.9
Mulundi	20.6	15.9	39.8	54.7	32.7
IYT Bulk 1977/11	23.2	19.8	44.7	40.6	32.1
Ikiela/1	31.7	8.9	39.6	42.2	30.6
Kibombwe/1	25.0	22.8	23.8	48.1	29.9
30572 1977/24	13.5	15.6	20.8	63.1	28.3
PYT Bulk 1977/69	31.4	11.1	42.9	25.9	27.8
Eala 07/4	24.3	12.9	38.4	31.6	26.8
Maguru	25.9	11.9	40.9	26.9	26.4
30395 1977/11	21.9	7.3	40.5	30.6	25.1
IYT Bulk 1976/6	12.3	8.2	19.2	59.4	24.8
Kiryumukwe/21	20.1	15.6	26.8	34.7	24.3
IYT Bulk 1976/9	15.9	6.2	27.8	46.9	24.2

were selected. The purpose of the trial was to screen the one or two best varieties for propagation and distribution in a rural environment.

Future Prospects and Conclusions

As a result of the initial findings, research will concentrate on:

- Development of a hybrid-producing program designed to improve local varieties, i.e., Eala 07, Creolinha, Maguruyinkware, which have the advantage of being well adapted to Rwanda's ecological conditions but the drawback of being susceptible to diseases. Crossing the best varieties in the selection with local varieties should produce highly productive offspring that are both disease-resistant and adapted to the country's ecological conditions. This hybridization program is to begin in 1984.
- The best varieties from screening will be tested in a rural environment in the Bugesera and Gisaka-Migongo regions as part of a joint study with the farming-system program. This program receives financial aid from the World Bank via the Bugesera-Gisaka-Migongo (BGM) project that has been operating in the region for close to 6 years. Scientific support is provided by IITA, which has supplied two scientists to work in the program. Variety tests in a rural environment will begin with the 1983–84 growing season.
- Trials on cultural methods (planting dates, mixed cassava cropping, mode and method of planting) will be conducted, and the Karama station is to pursue its work on the rapid propagation of the most promising cassava varieties.

I wish to thank Dr S.K. Hahn, the director of IITA's root-crop program, who visited the ISAR project on two occasions, advised judiciously, and offered encouragement. Thanks also go to all those who have helped in the program and without whom this work could not have been satisfactorily completed. Also, I am grateful to ISAR and IDRC for making it possible for me to attend this symposium.

EFFECT OF VARIETY AND PLANTING TIME ON THE YIELD OF CASSAVA IN MALAWI

R.F. NEMBOZANGA SAUTI[1]

In trials conducted at Bvumbwe and Baka research stations in Malawi, three cassava varieties — Chitembwere, Mbundumali, and Gomani — were planted at monthly intervals in an attempt to determine the effect of different planting dates on yields. At both sites, yields were highest for crops planted in January. At Bvumbwe, there were highly significant differences between varieties, whereas time of planting had a marked effect at Baka.

Although Malawi has distinct dry (April–October) and wet (November–March) seasons, cassava is planted throughout the year, particularly in the north in dambos (depressions prone to some waterlogging) and in areas that receive some rain during the dry season, such as Nkhata Bay. In some parts of the country, planting of cassava continues to April or May, and the roots are harvested the following year at about the same time.

Current government recommendations are to plant rainfed crops with the first rains. But farmers cannot afford to plant all the crops at once. Therefore, despite its importance as a food crop, cassava is generally planted late in the season, whereas maize, groundnuts, and tobacco are given priority.

Ezedinma et al. (1981) found that yields of fresh cassava were not affected significantly by planting dates but that late plantings produced the highest dry-matter yields. Okigbo (1971) showed that cassava planted later than June in Nsukka, Nigeria, produced higher yields of storage roots than did that planted earlier. These findings were in agreement with those from CIAT (1974).

I conducted trials of three cassava varieties to determine the optimal time of planting under rainfed conditions in Malawi at two locations — Bvumbwe and Baka research stations. Baka is located in northern Malawi with annual rainfall 1070 mm. Bvumbwe is in the southern part of the country in the Thyolo district; its mean annual rainfall is 1200 mm. Bvumbwe receives its planting rains about November, and Baka expects its planting rains from mid December to early January. Baka, which is 455 m above sea level, has a mean annual temperature of 25°C, and Bvumbwe, which is 1146 m above sea level, has a mean temperature of 19.3°C.

MATERIALS AND METHODS

Three commonly grown varieties, Chitembwere, Mbundumali, and Gomani, were selected. Chitembwere and Mbundumali are "sweet" varieties, whereas Gomani is "bitter." Chitembwere and Gomani have field resistance to cassava mosaic disease but Mbundumali is susceptible. Nevertheless, Mbundumali is preferred by people in the northern region; they claim that the mosaic-infected leaves are the best vegetables. Planting materials were collected from mosaic-free plants of similar age.

The experiment was a randomized block design, replicated three times, in a 3^4 factorial arrangement. The plots comprised four ridges 10 m long and two ridges 8 m long. Plant spacing was 90 cm × 90 cm, which is the standard spacing recommended for the planting of maize in Malawi. There were four plantings at monthly intervals starting in November at Bvumbwe and in January at Baka. Harvesting was also done at monthly intervals starting in January at both sites.

RESULTS AND DISCUSSION

Results at Bvumbwe (Table 1) showed that there were significant differences ($P < 0.01$) between varieties. Tests on varietal means showed that both Chitembwere and Mbundumali signifi-

[1] Makoka Research Station, Thondwe, Malawi.

Table 1. Cassava yield, number of roots/plant, and plant height at Bvumbwe (1979–80) and Baka (1980).

Planting date (day/ month/year)	Yield (kg/ha)			Roots/plant			Plant height (cm)		
	Chitembwere	Mbundumali	Gomani	Chitembwere	Mbundumali	Gomani	Chitembwere	Mbundumali	Gomani
Bvumbwe									
3/11/79	21813	24000	20689	8	9	5	249	242	210
3/12/79	30750	23813	19438	9	6	4	261	269	244
3/01/80	31594	25563	24875	10	6	8	274	262	255
4/02/80	19219	20406	8844	6	6	4	264	253	248
Baka									
11/1/80	24406	16906	16469	11	8	5	210	195	165
12/2/80	16719	10969	14688	9	7	5	165	225	155
13/3/80	10063	12719	13844	5	5	5	188	195	295
18/4/80	13688	3875	19125	4	3	4	213	118	213

cantly outyielded Gomani, but the difference between Chitembwere and Mbundumali was not significant. The increase in yield reflects significantly ($P < 0.001$) greater numbers of roots/plant (Table 1). The differences in yields attributable to time of planting were not significant. These findings do not agree with those of Ezedinma et al. (1981) that cassava planted early tends to be more vigorous than that from later plantings.

In contrast, at Baka (Table 1), there were no significant yield differences between varieties, but there were significant differences ($P < 0.05$) between planting dates. The highest mean yields were obtained from crops planted in January and the lowest mean yields were from March plantings. Gomani's yield was highest from the April planting, but the reason is not clear. Yield loss caused by delay in planting was materially high for Mbundumali.

The results obtained from Baka are in marked contrast to those found at Bvumbwe and also to results reported elsewhere (Okigbo 1971; CIAT 1974; Ezedinma et al. 1981). The most significant observation about these two trials is that, at both sites, January plantings outyielded all other plantings except for Gomani at Baka.

I am grateful to Dr Maida, E. Nyirenda, and staff at both Baka and Bvumbwe research stations who were involved in carrying out the trials. I also owe thanks to the staff of the biometrics unit at Makoka, especially A. Chirembo and F. Kisyombe as well as to O. Itimu, E. Matabwa, and M. Chibambo for their help. Finally, my sincere thanks go to D.R.B. Manda, Makato, and Brian Beck for their useful suggestions and to the Secretary for Agriculture for approving this paper.

RESPONSE OF CASSAVA TO FERTILIZERS AND TOWN REFUSE UNDER CONTINUOUS CROPPING

S.O. ODURUKWE AND U.I. OJI[1]

We sought to determine whether, and at what levels, NPK fertilizer and compost could be used to sustain continuous cropping with cassava. NPK and compost were each tested at three levels. Experimental design was 3^4 factorial arranged in nine incomplete blocks of nine treatments. The experiment lasted 4 years (1974–76 and 1978). Results showed that only K consistently affects root yield significantly. There was a decline in yield with years of continuous cropping — for 1975, 1976, and 1978, respectively, 33.8%, 45.8%, and 49.1%. The yield decline was attributed to depletion of trace and minor elements, proliferation of pests and diseases, and physical deterioration of the soil. Under the heavy rainfall common in the area, the fertility and productivity of the soil could not be maintained by application of fertilizers and refuse.

The experiment described in this paper was designed to test the feasibility of maintaining the fertility and productivity of a soil continuously cropped with cassava by application of fertilizers and town refuse and to determine the levels of NPK and compost that would sustain such a system.

METHODS AND MATERIALS

The design of the experiment was 3^4 factorial arranged in nine incomplete blocks of nine treatments. The factors and their levels were nitrogen: 0, 22, and 44 kg/ha as ammonium sulfate; phosphorus: 0, 17, and 34 kg/ha as triple superphosphate; potassium: 0, 45, and 90 kg/ha as muriate of potash; and compost: 0, 10, and 20 t/ha. The compost was actually town refuse collected from the dumps in Umuahia and sifted so that the broken bottles, pieces of wood, iron, and polyethylene materials were removed.

The site was a sandy loam soil on the Western Farm of the National Root Crops Research Institute (NRCRI) at Umudike. The initial characteristics of the soil were pH 4.98 ± 0.12; total nitrogen 0.08 ± 0.03%; organic carbon 1.4%; available phosphorus 6.39 ± 2.48 ppm; and exchangeable calcium, magnesium, and potassium, respectively, 0.53 ± 0.22 meq/100 g, 0.61 ± 0.12 meq/100 g; and 0.22 ± 0.42 meq/100 g.

The experiment was carried on for 4 years (1974–76 and 1978). At the beginning of each cropping season, the sifted refuse was applied in the furrows of the ridges of the previous year and then ridged over manually. The cassava cultivar Nwugo, a local best, which is early maturing, was used and was always harvested at 12 months. Cassava population density was 6700 stands/ha; gross and net plot sizes were 0.012 and 0.009 ha,

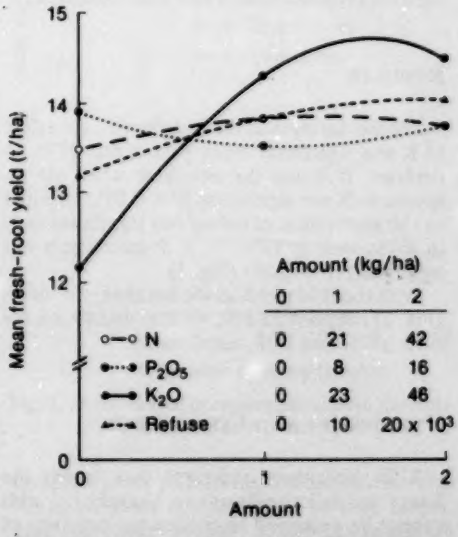


Fig. 1. *Mean response of cassava to fertilizers and town refuse on soils continuously cropped for 4 years.*

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

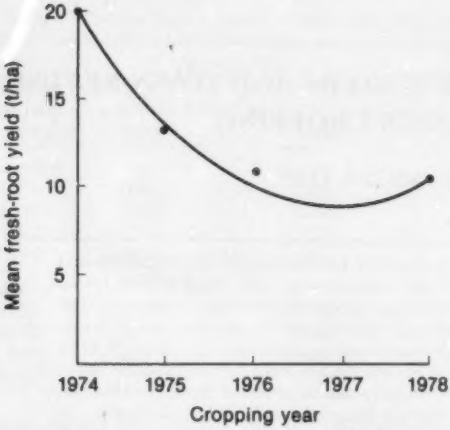


Fig. 2. *Declines in root yield of cassava during 4 years of continuous cropping on soils annually supplemented with fertilizer and town refuse.*

respectively. The fertilizer was applied in rings around the plants at 4 weeks after planting.

Because of the high prevalence of pest damage, stand count was used as a covariate. The results at the end of each season were analyzed statistically. A combined analysis was done for the four croppings after the homogeneity of variances for the 4 years had been confirmed.

Results

For the duration of the experiment, the effect of K was significant every year except 1978. In contrast, 1978 was the only year when the response to N was significant ($P < 0.05$); response to the application of refuse was significant only in 1975; and, in 1974, N × P interaction was significant ($P < 0.05$) (Fig. 1).

With the 1974 yields as the baseline, the yields (Fig. 2) declined 33.8%, 45.8%, and 49.1% for 1975, 1976, and 1978, respectively.

Discussion and Conclusion

This experiment indicates that, under the heavy rainfall conditions at Umudike, yields cannot be sustained in continuous cropping of cassava by yearly fertilizer, compost dressings. A resting period or fallow is necessary. This was also the finding in a companion experiment (Odurukwe and Oji 1981) where yields of yam, maize, and cassava, as well as total productivity declined with years of continuous cropping. Results from earlier work (Obi 1965) indicated that maize, yam, and cassava gave their best yields when preceded by bush fallow and worst yield when succeeded by themselves. Yields of a second crop of yam, maize, and cassava declined to 68%, 83%, and 60%, respectively, of the 1st year's yields. Similarly, in the forest zone of Ghana, soils maintained under a continuous rotation of maize and cassava for 8 years showed a steady decline in yield, even with soil amendment with compost and fertilizers (Nye and Greenland 1960).

Reports in the literature tend to indicate that, under other ecological conditions, yields can be sustained in continuous cropping by fertilizer application. Donnison (1961) showed that in the southern guinea zone of Nigeria, the usual 3-year fallow following the cropping cycle was unnecessary if farmyard manure were supplied at a rate of 5 t/ha. Similar results were obtained at Kano with guinea corn, millet, and groundnuts (Obi 1965) and in the savanna zone of Ghana under continuous rotation of maize and cassava (Nye and Greenland 1960). The discrepancies among the results obtained from the heavy rainfall vs savanna zones probably reflect the rapid leaching of nutrients and decomposition of organic-matter common in the humid tropics.

Considering the levels of fertilizers used in this experiment, we believe the yield declines reflect a depletion of the trace and minor elements contained in the soil, proliferation of pests and diseases, and physical deterioration of the soil. Continued use of ammonium sulfate lowers the pH of the soil and results in depletion of divalent cations, and regular application of phosphorus may promote potassium deficiency (Djokoto and Stepheus 1961).

The results of this experiment are controversial, particularly with respect to responses to compost application. Perhaps the poor response to compost application stemmed from the use of town refuse rather than rural household refuse, the former varying widely from day to day and location to location.

We wish to express our thanks to the Director of the National Root Crops Research Institute, Umudike, for granting permission for publication of this paper. The experiment was designed and initiated in 1974 by Dr J.B. Okeke and carried through 1976 under the late J.K. Obi. Their contributions are acknowledged.

RAPID MULTIPLICATION OF CASSAVA BY DIRECT PLANTING

N.T. DAHNIYA AND S.N. KALLON[1]

The possibility of rapidly multiplying cassava by planting short, hardwood stakes and soft-stem tops into the field was investigated. The results suggest 1-, 2-, 3-, and 4-node hardwood stakes could be planted directly into the field under the wet, tropical conditions of Sierra Leone. Young stem tops could also be used, if two tops were planted per stand.

Cassava has a slow rate of propagation, only 10–30 times/year (Cock et al. 1976), but Wholey and Cock (1973) have shown that unlignified shoot tips, when planted under mist, produce roots during the 2nd week and may be transplanted into the field after a further 10-day hardening. Kamalam et al. (1977) induced sprouting of stakes with as little as one-half node, but Lozano et al. (1977) reported that stakes with 1–3 nodes sprout poorly under field conditions because their size makes them susceptible to rapid dehydration. Stakes with more than 10 nodes have a better chance of surviving but mean more propagating material per unit area.

Within the past few years, several improved cassava clones with high yields and disease resistance have been released by research workers in Sierra Leone. The demand for planting material of these clones has exceeded supply because of the slow rate of crop multiplication and the enormous amount of planting material required for each stand. One way to reduce the latter is to plant shorter stakes, and this possibility is especially attractive in countries like Sierra Leone where rainfall is abundant.

MATERIALS AND METHODS

We investigated this possibility at the experimental farm of Njala University College, University of Sierra Leone, on upland, gravelly soil classified as Orthoxic Palehumult (Odell et al. 1974).

The experimental design was a randomized complete block with six treatments and four replications. Each plot consisted of four ridges, each 5 m long, 1 m high, spaced 1 m apart. On 21 May 1980, 1-, 2-, 3-, and 4-node hardwood stakes, young stem tops, and hardwood stakes,

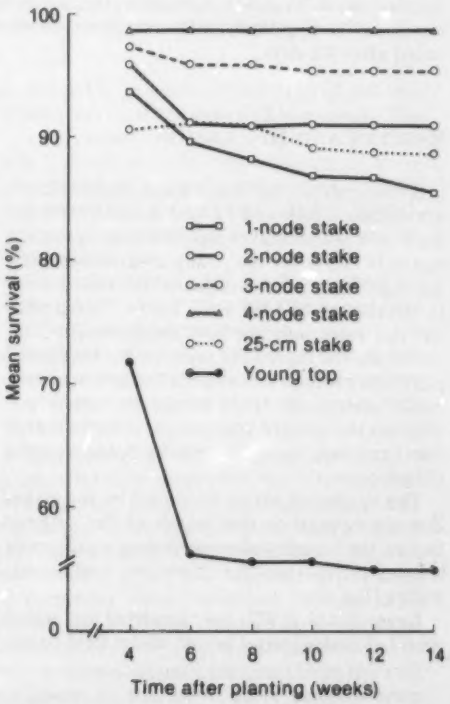


Fig. 1. *Mean survival of cassava plants from five stake sizes and young tops.*

[1] Agronomy Department, Njala University College, University of Sierra Leone, Freetown, Sierra Leone.

25 cm long, were planted 50 cm apart. The cassava variety was Nucass 1.

The single-node stakes averaged 4.3 cm long, and the 2-, 3-, and 4-node stakes were 7.3 cm, 10.8 cm, and 16.1 cm. The soft, young tops had an average diameter of 0.9 cm and were 15 cm long.

The 1-, 2-, 3-, and 4-node stakes were planted horizontally, the young tops vertically with about half their lengths underground, and the 25-cm hardwood stakes in an inclined position. Percentage sprouting was noted 4 weeks later, and, thereafter, survival, plant height, and number of stems were recorded fortnightly, with the two centre rows of each plot serving as sampling units. The plots that were entirely rainfed were weeded twice, 33 and 59 days after planting. No fertilizers were applied, and the study was terminated after 101 days.

Results and Discussion

Sprouting reached 98.8% for the 4-node hardwood stakes, followed by 97.5% and 96.3% for the 2- and 3-node stakes, respectively. Sprouting was only 71.9% for the young tops, and survival was significantly lower than for the others (Fig. 1), decreasing to 55% at 14 weeks. These poor survival rates indicate how small the food reserves are for the young tops. In the horizontal plantings (4-node stakes), the buds would have been protected from rapid dehydration, whereas the upright young tops, with their high water content, would have been liable to rapid dehydration.

The heights of plants produced by the stakes directly related to the length of the original stakes, the 1-node stakes producing significantly shorter plants than the 25-cm, 4-, and 3-node stakes (Fig. 2).

Lozano et al. (1977) have reported that stakes with 1–3 nodes sprout poorly under field conditions because their size makes them extremely susceptible to rapid dehydration. However, the present study demonstrates that there were no significant differences in the sprouting and survival percentages among the 25-cm, 4-, 3-, 2-, and 1-node stakes, which were in all cases higher than 90. This suggests that 1-, 2-, 3-, and 4-node stakes can be multiplied by direct field planting under the wet, tropical conditions of Sierra Leone.

Although Wholey and Cock (1973) reported that softwood stakes do not establish under field conditions, 55% of the young tops in this study survived at least 14 weeks. These findings indicate that young tops can be directly planted in the field, 2 plants/stand to offset poor survival.

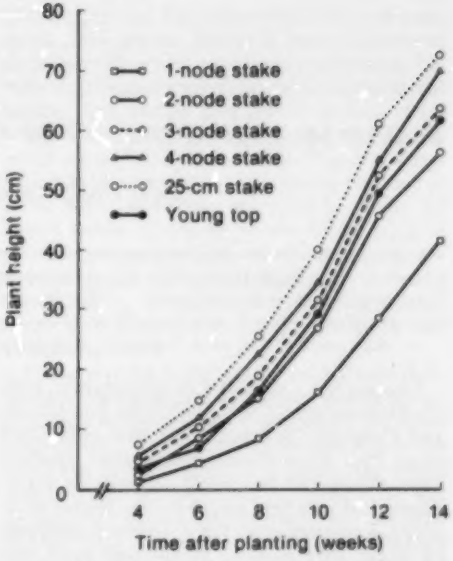


Fig. 2. *Mean height of cassava plants derived from five different-sized stakes and young tops.*

EFFECTS OF SHADE, NITROGEN, AND POTASSIUM ON CASSAVA

I.N. KASELE,[1] S.K. HAHN,[2] C.O. OPUTA,[3] AND P.N. VINE[3]

We studied the effects of shade, nitrogen, and potassium on the formation of tuberous roots in cassava. In pot experiments, shade delayed initiation of bulking by about 40 days and reduced tuberous cell size and number as well as dry-matter diversion to tuberous roots. Tuberous roots were detected in plants treated with potassium earlier than in unfertilized plants. Nitrogen did not affect tuberization but significantly increased numbers of tuberous roots. Root diameter and weight, storage-cell size and number, and dry-matter allocation to roots were significantly greater in plants supplied with potassium, alone or in combination with nitrogen, but were significantly reduced by nitrogen applied without potassium.

Tuberous-root initiation and growth constitute important yield determinants in cassava, as well as other root crops. Yield components in cassava comprise number and individual weight of roots, root volume and density, and storage-cell number and size. Our objective was to investigate how these yield components are affected by environmental factors; specifically, we sought to determine the effects of shading, nitrogen, and potassium on tuberous-root initiation and development in cassava.

MATERIALS AND METHODS

Topsoil to a depth of 0–15 cm was randomly taken from Ikenne Experiment Station of the International Institute of Tropical Agriculture (IITA) (about 60 km south of Ibadan, Nigeria). This soil is classifed under the Oxic Paleustalf, Alagba soil series (Greenland 1981) and is 8.5% silt; 9% sand; 82.1% clay. It has a pH 6, organic matter 1.3%, total N 0.1%, phosphorus (Bray-1 P) 1.9 ppm, exchangeable Ca 3.3 ppm, exchangeable Mg 19 ppm, and exchangeable K 17 ppm. Stem cuttings (25 cm, 2–2.5 cm in diameter, with five or six buds) were collected from the bottom portion of 4-year-old TMS 30572 plants and planted in pots containing 20 kg of soil that had been air-dried and sieved (2-mm mesh). The treatments were:

- N,K fertilizer combination (each of these rates: 0, 240, and 480 ppm) in urea (45% N) and muriate of potash (60% K_2O). The fertilizers were thoroughly mixed with soil before planting;
- A basal dressing of 50 ppm P (single superphosphate, 18% P_2O_5) was also mixed with soil before planting; and
- Shading at two levels, 100% and 70% of normal light intensity, was induced by a bamboo frame placed over the pots and covered with palm fronds.

A split-pot design with three replications having shade levels as main plots and NK combination as subplots was used. Light intensity and air temperature were regularly measured with a light sensor (Terry's 80/1) and hygrothermograph model 8368-00, respectively. Plants (4/treatment) were harvested 20 days after planting and at 20-day intervals up to 180 days. Root samples (3 cm long) were taken from proximal portions at about 1 cm apart from the root attachment to the stem. Root samples were killed and fixed in formalin acetic alcohol (FAA) with a vacuum pump (Berlyn and Miksche 1976). Anatomical studies were carried out on thin-root transections obtained by free-hand sectioning with a razor blade. Root transections were stained with iodine solution to detect starch grains, the criteria for differentiation of tuberous roots from feeder roots. Days to the onset of tuberization; tuberous-root numbers

[1] Programme national manioc (PRONAM), Kinshasa, Zaire.
[2] International Institute of Tropical Agriculture, Ibadan, Nigeria.
[3] Department of Agronomy, University of Ibadan, Nigeria.

Table 1. Plant characteristics measured as affected by shading, nitrogen, and potassium.[a]

Fertilizer combination (ppm)		Days to the onset of tuberization	Storage cell		Tuberous root					Shoot dry weight (g/plant)	Tuberous-root production	
							Weight					
N	K		Number[b]	Site (μm)[b]	Number	Diameter (mm)	Total fresh (g/plant[b])	Individual (g)	Total dry (g/plant)		Efficiency[c]	Plant weight at initiation (g)
Unshaded												
0	0	40	46f	45cd	5de	13c	52.5d	10.5c	7.0f	172.5c	0.04d	24.4bc
0	240	20	120bc	75b	6d	31b	115.8bc	19.3b	22.5d	165.0c	0.10b	19.2c
0	480	20	190a	88a	7d	39a	211.4b	30.2a	28.0c	150.0d	0.21a	16.3c
240	0	40	40f	43c	11bc	12d	110.0c	10.0c	20.5d	222.5a	0.03d	28.6b
240	240	20	133b	85a	15a	34a	337.5a	22.5a	44.5b	212.5a	0.08b	32.4a
240	480	20	171a	91a	16a	38a	425.6a	26.6a	66.5a	195.0b	0.20a	44.0a
480	0	40	37f	41c	14ab	11de	134.4b	9.6c	25.0cd	255.0a	0.02d	29.4b
480	240	20	126b	78b	19a	33ab	351.5a	18.5b	51.0a	240.0a	0.06c	31.5ab
480	480	20	142ab	82ab	17a	35a	440.3a	25.9a	60.0a	232.5a	0.15a	36.2a
Shaded												
0	0	80	22g	14g	2f	6f	7.8f	3.9d	2.5g	192.5b	0.02d	12.4e
0	240	60	50f	20f	3ef	8e	38.1e	12.7c	10.0e	180.0bc	0.04d	10.8e
0	480	60	104c	33d	3ef	15c	25.5e	18.5b	12.5e	167.5c	0.09b	9.1e
240	0	80	16g	8h	7d	5f	21.0e	3.0d	6.0f	232.5a	0.01d	16.1c
240	240	60	62e	30de	9c	11de	95.4c	10.6c	19.0a	225.0a	0.05cd	17.6c
240	480	60	88d	35d	10c	14c	161.0b	16.1b	24.0cd	212.5a	0.08b	19.3c
480	0	80	11g	11g	8cd	4f	28.0e	3.5d	8.0f	267.5a	0.01d	16.9c
480	240	60	56e	34d	12b	10e	128.4bc	10.4c	20.2d	255.0a	0.03d	16.0c
480	480	60	72d	27e	13b	13c	185.9b	14.3c	22.0d	242.5a	0.07bc	18.0c

[a]Figures with same letter in the same column are not significantly different at 5%.
[b]Data collected at 6 months after planting.
[c]Estimated according to Boerboom's (1978) model for cassava.

and diameter; total and individual fresh and dry weight of roots; shoot dry weight; and storage-cell size and number/root radius were recorded. Dry-matter diversion to tuberous roots was estimated by Boerboom's (1978) model for cassava. Analyses of variance and tests of significance were carried out on all parameters. The contribution of important parameters likely to influence tuberous-root yield was estimated from single correlation coefficients.

Results

Shaded conditions caused changes in microclimate (Table 1). The air temperature under shaded conditions ranged from 4.3° to 4.4°C lower than unshaded conditions. Light intensity in shaded conditions ranged from 0.32 to 0.46 watts/m^2 in shaded and from 0.46 to 0.65 watts/m^2 in unshaded conditions.

Shade delayed tuberization markedly (Table 1) and significantly reduced all the yield parameters measured except shoot dry weight. Tuberization was detected earlier in plants treated with K alone or in combination with N (at 20 and 60 days in unshaded conditions respectively) than in plants treated with N alone (at 40 days under unshaded, 80 days under shaded conditions). In addition, plants supplied with K alone or in combination with N had significantly more storage cells than unfertilized plants, whereas no significant differences were observed between nitrogen-treated plants and unfertilized plants. The most storage cells (190) were recorded on plants treated with 480 ppm K. Storage-cell size was significantly increased by the application of K alone or in combination with N and was slightly reduced by N applied alone. The biggest storage cells were recorded in plants treated with 240 ppm N and 480 ppm K in unshaded conditions. The application of N alone or in combination with K increased the numbers of tuberous roots, and plants treated with 480 ppm N and 240 ppm K in unshaded conditions produced the most roots. The application of K alone resulted in slight increases in tuberous roots over unfertilized plants.

Root diameter was slightly reduced by N applied alone and significantly increased by K applied alone or in combination with N. The biggest roots were recorded on plants treated with 480 ppm K in unshaded conditions. The reduction in total fresh weight caused by shaded conditions ranged from 60 to 70%. Generally, the fertilizer treatments had beneficial effects on total fresh weight of tuberous roots, with the heaviest (440 g/plant) being recorded on plants treated with the combination of 480 ppm N and 480 ppm K. The combinations of N and K outyielded all applications of N or K alone. The increase in shoot dry weight caused by shade was 1–2%, with the heaviest being recorded from plants supplied with 480 ppm N in shaded conditions. Potassium applied alone slightly reduced shoot dry weight. All fertilizer treatments benefited root dry weight. The highest root dry weight (66.5 g/plant) was recorded on plants treated with 240 ppm N and 480 ppm K in unshaded conditions.

The correlation (Table 2) between root dry weights (yield) and root numbers, individual weights, diameters, and storage cells was highly positive, but the highest correlation was observed between root dry weights and root numbers ($r = 0.981$). High positive correlations were also observed between dry weights and fresh weight of individual roots ($r = 0.962$) and be-

Table 2. Correlation between some important parameters that affect yield in cassava.

	Tuberous root				Storage cell	
	Root dry weight	Individual weight	Number	Diameter	Number	Size
Tuberous root						
Dry weight	1.000					
Individual weight	0.782	1.000				
Number	0.981	0.406	1.000			
Diameter	0.702	0.962	0.413	1.000		
Storage cell						
Number	0.744	0.733	0.214	0.984	1.000	
Size	0.464	0.221	0.202	0.774	0.393	1.000

tween root diameter and storage cells (0.984).

Discussion

The effect of potassium on marginal distribution of dry matter to tuberous roots was the outstanding feature. Potassium applied alone or in combination with N encouraged dry-matter diversion to tuberous roots, whereas shaded conditions discouraged this allocation. Plant weight at the initiation of tuberous-root production was reduced by shaded conditions.

Tuberous-root initiation in cassava depends on carbohydrate supply from the aboveground parts to the roots in the early stages of growth (Hunt et al. 1977). Our results show the importance of K in assimilate translocation in cassava (Kumar et al. 1971) and could partly explain why tuberous roots were detected first in plants treated with K. Nitrogen can promote excessive shoot growth at the expense of root growth (Malavolta et al. 1955) — a fact that may explain the delay in tuberization observed on plants supplied with N alone. The delay in tuberous-root initiation recorded on shaded plants may be attributed to the inadequate carbohydrate supply to the roots (Asher and Azanne 1966).

The anatomical changes during tuberization were similar in all treatments in this experiment. Interesting differences were observed in the number and size of storage cells. Storage cells were increased in plants treated with K, lower in shaded plants and plants treated with N alone. These results strongly agree with observations of sweet potato by Murata and Akazawa (1968, 1969) cited by Hahn and Hozyo (1980). They found that potassium accelerated cambium activity of the root and that nitrogen decreased cambium activity and increased lignification. They also indicated that shade decreased cambium activity and lignification.

The effects of nitrogen and potassium on tuberous-root numbers were similar to observations reported by Chaddha (1958) and Ngongi et al. (1977). The authors found that N increased, and K decreased, numbers of tuberous roots. Nitrogen promotes shoot growth at the expense of root bulking but increases numbers of roots, an indication that the buildup in photosynthesis probably provides enough assimilate to initiate roots.

Root enlargement is through the synthesis and accumulation of starch (Hunt et al. 1977). Increase in tuberous-root volume depends on the increase in cell numbers (through cell division) and their expansion (Tsuno and Fujise 1964). In our study, numbers and size of storage cells were both positively correlated with diameter, but number was the more important determinant. Increase in individual weights of roots of plants treated with K was attributed to increases in root diameter. Any factor that can increase the numbers of storage cells can increase final yield, as was clearly the case with K alone or in combination with N. Likewise, any factor — such as shade — that reduces storage-cell numbers will adversely affect yield. Increase in total weight recorded on plants with the combination of K and N was attributed to increased numbers and weights of individual tuberous roots. Our data on dry-matter distribution in tuberous roots fitted the model proposed by Boerboom (1978).

Plants treated with K were able to channel more dry matter to their roots than were other plants. This was mainly attributed to the role of K in accelerating assimilate translocation to the roots (Malavolta et al. 1955; Tsuno and Fujise 1964). Shade discouraged the diversion of dry matter to the roots in all fertilizer treatments, probably a reflection of the lower production of shaded plants and the high stem requirements for assimilates (Hunt et al. 1977). Similar results were found by Fortwin and Omta (1980) on *Solanum nigrum*.

WEED INTERFERENCE IN CASSAVA–MAIZE INTERCROP IN THE RAIN FOREST OF NIGERIA

RAY P.A. UNAMMA AND L.S.O. ENE[1]

In 1981–82, we conducted studies of cassava and maize intercropped on sandy loam in the rain-forest zone of Nigeria to determine when and how long the plants had to be kept weed-free. The major weeds present in the control (8 weeks after planting) were mainly annual broadleaves, grasses, and sedges. The broadleaves included *Boerhaavia diffusa*, *Calapogonium mucunoides*, *Cleome ciliata*, *Commelina benghalensis*, *Eupatorium odoratum*, *Euphorbia hirta*, *Talinum triangulare*, and *Trianthema protulacastrum*; the grasses comprised mainly *Andropogon gayanus*, *Brachiaria deflexa*, *Cynodon dactylon*, *Digitaria horizontalis*, *Panicum maximum*, *Paspalum orbiculare*, and *Setaria barbata*. Uncontrolled weed growth caused a 2-year average loss of $5607/ha in yield value compared with the mixture kept weed-free from planting to maturity. Average value of yield for 2 years ($9206/ha) from the cassava–maize intercrop was much higher than that for the sole crops, although yield in grain and roots was lower. The yield of the crop mixture was depressed by weed interference during the first 4–8 weeks; however weeds emerging after this period did not significantly impair the yield.

Nigeria and Zaire are the leading cassava producers in the humid and subhumid regions of Africa where about 67% of the continent's 4.4×10^7 t of cassava is produced (Jennings 1970; Tan and Bertrand 1972; FAO 1978). The farmers in Nigeria intercrop cassava with maize (Okigbo 1978) and control weeds by hoeing after they have finished planting (2–4 weeks). As it is neither economical nor feasible to keep a crop weed-free all season, knowledge of the time when weeds must be removed to minimize yield loss is crucial. Both maize and cassava have been shown to be sensitive to weed infestation — the former for the first 4 weeks and the latter for the first 10–12 weeks after establishment (Nieto et al. 1968; Onochie 1975). Information is lacking on the critical period of weed interference in a cassava–maize intercrop.

Our objectives in carrying out the present studies were:

- To determine the magnitude of weed interference in cassava intercropped with maize; and
- To define when and how long control is crucial, with a view to suggesting the most appropriate time to weed the crop mixture.

MATERIALS AND METHODS

The experiment was conducted in 1981 and in 1982, located on acid ferralitic (sandy loam) soil at the research farm at the National Root Crops Research Institute (NRCRI), Umudike, in the rain-forest zone of Nigeria. The site was plowed, harrowed, and formed into ridges (100 cm apart). The two crops were planted the same day, cassava (TMS 30211) at 100 cm apart along the crests of the ridges and maize (FARZ7) at 3 stands/hole, also 100 cm apart but on both sides of the ridges and between cassava stands. The maize was thinned to 2 plants/stand 2 weeks later. The experiment was a randomized complete block design, with three replications/treatment.

Planting was done each year near the onset of rain. Maize was harvested at 4 months and cassava at 10 months. Two treatment schemes were employed. In one ("weed-free"), the cassava–maize mixtures were kept virtually weed-free (weeding every 2 weeks) for different lengths of time after planting. In the other ("weed-infested"), the mixtures were left unweeded after planting for different periods before being kept weed-free to maturity of the last crop in the plot. For comparison purposes, one cassava–maize mix was kept weed-free; another, weed-infested; and other mixtures weeded at

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

Table 1. Effects of duration of weed interference on maize grain and fresh-root yields of cassava–maize intercrop, Umudike, 1981–82.

	Yields (t/ha)			
	Maize[a]		Cassava	
Interference (weeks after planting)	1981	1982	1981	1982
Weed free				
Intercrop				
0–4	3.0	2.3	13.7	11.5
0–8	3.0	2.4	14.3	12.6
0–12	3.1	2.9	15.9	11.5
0–16	3.1	2.2	23.9	12.9
0–20	3.1	2.4	18.1	12.8
0–24	3.1	2.6	21.2	12.5
0–28	3.1	2.2	18.7	11.8
0–40	3.0	2.8	20.0	17.6
Sole cassava				
0–40	0.0	0.0	21.2	18.4
Sole maize				
0–16	3.4	3.8	0.0	0.0
Weed infested				
Intercrop				
0–4	2.9	2.9	14.5	11.5
0–8	2.1	1.7	13.4	12.1
0–12	2.1	1.3	10.9	5.2
0–16	2.1	1.4	10.9	4.4
0–20	1.9	1.7	7.7	3.2
0–24	1.9	1.3	6.7	0.8
0–28	2.4	1.2	5.9	1.2
0–40	2.4	1.4	7.9	1.4
Sole cassava				
0–40	0.0	0.0	8.0	3.7
Sole maize				
0–40	2.4	0.0	0.0	0.0
Weeded				
at 3	2.6	2.7	10.7	8.5
at 3, 8, 12	2.9	2.3	18.9	12.9
Coefficient of variation (%)	24.0	52.0	43.56	66.0

[a]Dry grain at 14% moisture content.

3 weeks, as well as at 3, 8, and 12 weeks after planting (WAP). Weed-free and weed-infested monocultures were included for evaluations of the effects of intercropping on the yields of the two crops. NPK fertilizer (15 : 15 : 15) was applied to all plots at 400 kg/ha. In 1981, the plot sizes were 4 m × 6 m; in 1982, 6 m × 6 m.

At harvest, yields were measured for the crops in the middle two ridges excluding the peripheral stands and were converted to a per-hectare basis for meaningful comparisons. The value of the yields was estimated from the prices of cassava and maize randomly sampled from the nearest local markets.

Results and Discussion

Based on the 2-year average of the results obtained, uncontrolled weed growth in cassava intercropped with maize significantly reduced

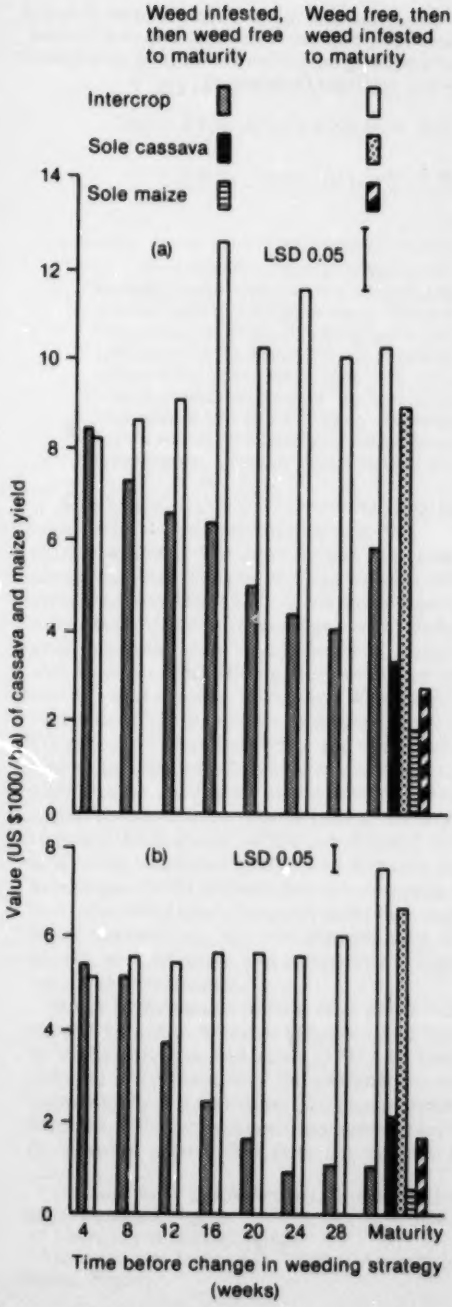


Fig. 1. *Effects of weed interference on value of yields of cassava and maize.*

the value of the intercrop by $5607/ha (Fig. 1). The loss was 40% for maize grain and 75% for cassava root yields. The weed-free sole maize outyielded the maize in the weed-free intercrop by 19%, whereas the weed-free cassava in the mixture was outyielded by 5% by the weed-free sole cassava (Table 1). However, the combined yield of the two crops in monetary terms was significantly better than that derived by either of the two sole crops (Fig.1).

Thus, the cassava was more sensitive to weed infestation than maize under intercrop conditions. On the other hand, the maize responded more negatively to the intercropping practice.

The dominant weeds at 8 WAP in the unweeded control were *Boerhaavia diffusa, Calapogonium mucunoides, Cleome ciliata, Commelina benghalensis, Eupatorium odoratum, Euphorbia hirta, Talinum triangulare*, and *Trianthema protulacastrum*, among the broadleaved weeds. The grasses included *Andropogon gayanus, Brachiaria deflexa, Cynodon dactylon, Digitaria horizontalis, Panicum maximum, Paspalum orbiculare*, and *Setaria barbata*. The dominant sedges were *Cyperus difformis, C. distans, Fimbristylis barteri, Kyllinga nemoralis*, and *Mariscus alternifolius*.

The first 4–8 weeks are the most critical for weed control. After this period, weeds are controlled by shade from the maize and cassava canopy. Uncontrolled weed infestation in monocultures reduced the maize grain by an average 54% and the cassava-root yields by 70% for the 2 years. Intercropping maize with cassava and leaving the crop unweeded depressed the maize yield by 52% and the cassava yield by 69%. This suggested that the maize and cassava canopy contributed to control of some of the late-germinating weeds.

The intercrop formed a canopy earlier in the season than did either of the sole crops and, thus, shortened the critical period for weed control in the cassava component from 10–12 weeks to 8 weeks. The critical period of weed interference for maize was the same (4 WAP) as reported for monoculture (Nieto et al. 1968). Keeping the crop mixture weed-free for the first 8 weeks was sufficient to overcome the adverse effects of the weeds. The differences in yield between 1981 and 1982 were attributed to differences in rainfall and soil fertility. However, low cassava yields despite improved varieties and recommended fertilizer rates (Hahn et al. 1979) in farmers' fields in Nigeria are probably a reflection of the farmers' failure to weed early enough in the critical period.

Increasing the population of the crops and applying a preemergence herbicide that is tolerated by both crops would ensure that the crops were protected during the critical period for weed control and would minimize yield losses.

We are thankful to the Director and the Board of Governors, National Root Crops Research Institute, for sponsoring this project and for granting us permission to report the findings.

CROP PERFORMANCE IN COMPLEX MIXTURES: MELON AND OKRA IN CASSAVA–MAIZE MIXTURE

J.E.G. IKEORGU,[1] T.A.T. WAHUA,[2] AND H.C. EZUMAH[3]

We conducted a 2-year investigation at Ibadan, Nigeria, to determine the economic benefits of including melon and okra in a cassava–maize intercropping system. Fresh-root yields of cassava were reduced by 28% by maize in the mixture but only by 3%, 6%, and 9% by okra, melon, or both, respectively. Intercropping had no adverse effect on the grain yield of maize; rather yield was 19% higher in the maize–cassava intercrop than in monoculture. Fresh-fruit yields of okra were reduced by 72%, 89%, and 56% in mixtures with cassava, cassava–maize, and cassava–maize–melon, respectively. Melon-seed yields were decreased by 56% and 76% in mixtures with cassava and cassava–maize, respectively. The cassava–maize cropping system yielded the highest amount of calories per hectare; however, total productivity per unit area of land was highest in the cassava–maize mixture with both okra and melon.

As a long-duration (9–18 months) crop, cassava is suitable for intercropping with plants that mature within 2–3 months (before the cassava canopies close). Okigbo and Greenland (1976) estimated that about 50% of the cassava grown in tropical Africa is intercropped with cereals, grain legumes, leafy vegetables, and fruits as well as tree crops. Although there are several reasons that farmers intercrop (Watters 1971; Norman 1975; Andrews and Kassam 1976; Okigbo and Greenland 1976), the most important is that total productivity per unit of land and total income are higher under intercrops than under monocultures. Furthermore, by intercropping, farmers reduce the risk of losing their base crop. Andrews (1972) and Kassam and Stockinger (1973) showed that intercropping is most rewarding when the crops make their maximum demands on the environment (soil nutrients, soil moisture and temperature, light, etc.) at different times.

Maize is the most common crop grown with cassava in Latin America (Moreno and Hart 1979), Asia (Kumar and Hrishi 1979), and Africa (Okigbo 1978) because of the productivity and compatibility of the mixture. The faster growing maize exploits the microenvironment earlier in the growing season than does the cassava. In Nigeria, maize is intercropped about 80% of the time (Okigbo 1977), and a cassava–maize intercropping package has been recommended to farmers by the National Accelerated Food Production Project (NAFPP 1977). Because cassava–maize constitutes the dominant mixture in many traditional intercropping systems, researchers have tended to ignore the other components of the systems — vegetables such as melon, okra, African spinach, fluted pumpkins, and even tomatoes. For instance, all over West Africa, melon (*Colocynthis vulgaris*) and okra (*Abelmoschus esculentus*) are popular, although little attention has been paid to them. In one study, Fagbamiye (1977) showed that melon performed poorly in cropping systems based on cassava, maize, and yams but improved the yields of the base crops. We examined the productivity of the cassava–maize mixture, with or without melon and okra, to see how the vegetables affected the mixture microenvironment.

MATERIALS AND METHODS

The study was conducted at the teaching and research farm of the University of Ibadan. The area has two rainy periods — one from April to July (early season), which accounts for most of the 1250-mm annual rainfall, and the other from August to November (late season). Our investigation was carried out during the early seasons

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.
[2] University of Ibadan, Nigeria.
[3] International Institute of Tropical Agriculture, Ibadan, Nigeria.

of 1981 and 1982 on sandy loam of Egbeda soil series (Oxic Paleustalf) classifed as Alfisols or Ferric Luvisols. Initial soil analysis indicated pH 6.5; organic matter 1.34%; total N 0.09%; 12.63 μg/g Bray-1-P; and exchangeable Ca, Mg, and K of 3.11, 0.72, 0.38 meq/100 g.

Two morphologically different cassava cultivars: TMS 30001 (sparse canopy, upright) and TMS 30572 (dense canopy, spreading) were combined with maize (TZPB), egusi melon, and an early maturing okra (V45) collected from the National Seed Service, Ibadan. Along with monocultures of each variety, we investigated cassava–maize–okra–melon; cassava–maize–okra; cassava–maize–melon; cassava–maize; cassava–okra; cassava–melon; and cassava–okra–melon, for each cassava variety.

The experiment was a split plot fitted into a randomized complete block design with three replicates. The two cassava cultivars formed the main plots and the various crop combinations formed the subplots. Each subplot was 8 m × 8 m.

The land was plowed and harrowed, and all crops were planted at the same time on the flat: the cassava at 1 m × 1 m; the maize (2 plants/hill) between the cassava rows also at 1 m × 1 m; the okra (2 plants/stand) was alternated with cassava within the row; and the melon was planted between the maize and cassava. Thus, the cassava population was 10 000/ha and that of the other components was 20 000 plants/ha, although, in 1982, the melon population was reduced to 10 000 plants/ha.

NPK fertilizer (15 : 15 : 15 — 200 kg/ha in 1981 and 400 kg/ha in 1982) was applied to all plots. Plots without melon were weeded twice (21 and 42 days after planting, DAP) and those with melon, only once (21 DAP).

The melons were harvested at 80 DAP and processed for seeds. Okra was harvested at 3–4-day intervals for 6 weeks, starting at 50 DAP. Maize was harvested 100 DAP, dried to 14% moisture, shelled, and weighed. Cassava was harvested at 10 months (ca 300 DAP), and roots were weighed fresh. All weights were extrapolated to yield/hectare.

We used analysis of variance for a split-plot design to assess treatment effects and compared means by Duncan's multiple-range test at the 5% level of significance. The differences attributable to cassava cultivar were not significant; therefore, the values presented in this paper are means for the two cultivars.

Results and Discussion

Cassava yields were significantly reduced by intercropping (Table 1); in combination with maize, the reduction was 28%. Kang and Wilson (1981) had earlier observed that TZPB maize decreased cassava yields more than an early maturing variety (TZE). The inclusion of okra, melon, or both in cassava–maize mixtures reduced cassava-root yields an additional 3%, 6%, and 9%, respectively.

Intercropping had no adverse effect on maize grain yield: rather, maize yields were 19% higher in the cassava–maize mix than in monoculture, and the reduced cassava yields were compen-

Table 1. Yields (t/ha) of cassava, maize, okra, and melon grown alone and in mixtures.[a]

	Cassava		Maize		Okra		Melon	
	1981	1982	1981	1982	1981	1982	1981	1982
Monoculture	25.46a	20.40a	2.29ab	2.96a	1.333a	1.512a	0.696a	0.724a
Cassava–maize	19.40b	13.42b	3.07a	3.17a	—	—	—	—
Cassava–maize–okra	17.79bc	13.79b	2.32ab	3.00a	0.088b	0.217b	—	—
Cassava–maize–melon	14.90c	15.32b	2.42ab	2.34a	—	—	0.191b	0.155b
Cassava–maize–okra–melon	16.40bc	12.61b	2.00b	3.26a	0.126b	0.267b	0.225b	0.122b
Cassava–okra	25.63a	20.10a	—	—	0.278b	0.523b	—	—
Cassava–melon	22.03ab	16.93bc	—	—	—	—	0.270b	0.360b
Cassava–okra–melon	18.55bc	16.96bc	—	—	0.388b	0.863b	0.221b	0.207b

[a]Means followed by the same letter(s) within a column do not differ at $P < 0.05$.

Cassava–maize (already harvested) mixes are popular wherever root crops are grown in the tropics.

Table 2. Comparison of calorie equivalents and land-equivalent ratios (LERs) obtained from sole cassava and from four intercropping systems involving cassava, maize, okra, and melon.

Combination	Mean for 2 years	
	Calories (1×10^7 cal/ha/day)	LER
Sole cassava	9.70	1.00
Cassava–maize	18.74	1.91
Cassava–maize–okra	16.80	1.81
Cassava–maize–melon	17.67	1.92
Cassava–maize–okra–melon	17.50	2.00

sated for by the increase in grain. The vegetables did not have any adverse effect on the maize.

Okra yields were reduced by 72%, 89%, and 56% in mixtures with cassava, cassava–maize, and cassava–maize–melon, respectively. Okra performed better in mixtures with melon than in those without, confirming earlier observations (IITA 1975; Fagbamiye 1977) that the yields from crops associated with melon are usually improved.

Yields of melon seed were significantly decreased in combinations with cassava.

All the crop combinations produced higher calorie equivalents and land-equivalent ratios than were obtained under monoculture cassava (Table 2). The cassava–maize mixture was superior to the other systems in terms of calories, whereas cassava–maize–okra–melon and cas-

sava–maize–melon were superior in terms of land-equivalent ratios. Traditionally, farmers prefer multicrop mixtures to satisfy their dietary needs. Further work is needed to determine the optimal crops and combinations.

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SOIL-CONSERVING TECHNIQUES IN CASSAVA AND YAM PRODUCTION

P.N. VINE, O.B. AJAYI, D.M. MITCHOZOUNOU, E.J. HOUNKPATIN, AND T. HOUNKPEVI[1]

In the belief that conventional land preparation for root crops accelerates soil erosion unnecessarily, we investigated the potential of some soil-conserving practices in the production of cassava and yam in Nigeria. We studied dry-season planting of cassava to hasten canopy development to protect the soil during the subsequent rainy season and we examined the effects of mulching and tillage on both cassava and yams. Dry-season cassava, when protected by insecticide or acaricide, yielded more than 30 t/ha at 14 months after planting. A certain amount of residual soil moisture at planting time was found necessary for crop establishment. In both the dry and the wet seasons, mulch aided cassava growth in some circumstances but not in others; however, it increased wet-season earthworm activity manyfold and reduced splash erosion. In fact, soil splash was reduced more by mulching than by omission of tillage both in the cassava and in the yam studies. In the latter, *Dioscorea alata*, planted in April 1983 with five soil treatments (no tillage; plowing only; plowing plus overall mulch; plowing and ridging; and plowing and building mounds) had best early growth on the flat treatments, and soil splash as well as soil slumping were drastically reduced by the mulch treatment. Other findings in the series of studies were that planting cassava stakes on a slant is suitable for both tilled and untilled plots and that the hardness of the soil does not appreciably affect the ease with which cassava roots can be pulled from the ground.

How physical management of the soil affects the growth of tropical root crops has been studied by several authors, including Okigbo (1966, 1973), Lal and Hahn (1973), Ferguson and Gumbs (1977), Vine (1979), and Lutaladio et al. (1982). Also, factors affecting development of the canopy, which is a form of soil cover, continue to be widely researched (Onwueme 1978). We have studied techniques for successful dry-season planting of cassava as a means of early establishment of canopy; mulching and zero tillage as tools to reduce soil splash; the role of soil strength in harvesting of cassava; and physical management of soil cropped with yam (*Dioscorea alata*).

MATERIALS AND METHODS

The experiments were carried out at the University of Ibadan, Teaching and Research Farm, Nigeria, on sandy Alfisols.

After the last rains in 1980 and in 1981, a field that was previously cropped with fertilized cassava was plowed to 20 cm deep and planted on 21 November 1980 and 27 November 1981. Cassava varieties TMS 30211 and TMS 30572 were used at 1 m × 1 m spacing. Dry-grass mulch was applied, at 7 t/ha in 1980 and just enough to give approximately 100% soil cover in 1981, to half the plots in a randomized complete block factorial, with four replications of 16 plants/plot plus double guard rows. Spraying of the small, slowly growing plants at 10-day intervals with 0.05% a.i. dimethoate completely eliminated grasshoppers (*Zonocerus variegatus*) and cassava green mite (*Mononychellus tanajoa*). The mulched and unmulched plots carried virtually identical growth and were treated as replicates. We harvested the 1980 crop, two replications at a time, at the beginning of the 1981 rains (4.5 months after planting — MAP), near the end of the rains (10.5 MAP), and in January 1982 (14 MAP). The 1981 crop was harvested at the beginning of the 1982 rains (4 MAP). Leaf-area index (LAI) was determined from the fresh weight of all the leaves from one plant per plot. We used a photoelectric meter to determine the leaf area/unit fresh weight.

In the middle of the dry season, on 15 January 1982, to determine factors affecting establishment of cassava, we planted TMS 30572 on unmulched, plowed land (previously under *Eupatorium* sp.) in a split-plot, randomized complete block design with four replications, the

[1] Department of Agronomy, University of Ibadan, Ibadan, Nigeria.

plots being split according to the age of the planting material and the moisture regimen: freshly cut stakes or stakes cut from planting material that had been stored vertically for 2 months under shade on moist soil; no water, 500 mL water, or 500 mL aqueous 0.1% aldrin (soil insecticide) solution per plant at planting time.

We also planted TMS 30572 in April 1983 (wet season) on land previously intercropped with maize and cowpea. The design was a randomized complete block factorial with four replications, where the treatments were plowed or unplowed soil; dry mulch (approximately 100% cover) or no mulch; and stakes planted vertically, on a slant, or horizontally. Before application of any of these treatments, the whole field was sprayed with paraquat at 0.5 kg a.i./ha. After the stakes were planted, all plots were immediately resprayed with a mixture of paraquat and diuron at 0.5 kg a.i./ha and 1.5 kg a.i./ha, respectively. Both crop growth and amounts of soil splash caused by rain were measured. For the latter, filter funnels were inserted into the ground with 4 mm above ground to catch the soil. The objective was to determine some cultural techniques for soil conservation in cassava production during the wet season.

We also measured the vertical force needed to remove 14-month-old cassava plants (TMS 30211 and TMS 30572) from the soil, using a lever and spring balance, just before the 1983 rains, after the first rains, and after enough rain had fallen to wet the soil at least 20 cm deep. On each occasion, two random plots of about 10 plants each within a uniform field were harvested. Lifted yield and amount of yield left in the soil were also measured. We examined the force required to lift the roots and the damage or breakage they sustained to see whether the soil hardness characterizing zero-tillage techniques affected the ease of harvesting.

In a study of land preparation and mulching for yam, land previously intercropped with maize and cassava was given five treatments in a randomized complete block design with four replications. The treatments — no tillage; plowing; plowing and mulching; plowing and ridging; and plowing and mounding — were done in the dry season, 1982–83. *Dioscorea alata* (variety TDa 297) setts, about 200 g each, were planted at 1 m × 1 m spacing after the rains started and were capped with dry grass. There were nine experimental plants per plot surrounded by a guard row. Along with yam-shoot emergence and early growth, soil splash was measured as well as soil slumping relative to steel rods that were driven 60 cm into the ground.

Table 1. Means of growth and development of dimethoate-sprayed cassava (TMS 30211 and TMS 30572) planted at the commencement of the dry seasons, 1980–82, in mulched and unmulched plots.[a]

Harvesting date	Leaf-area index	Storage roots/plant	Yield (t/ha)
1980–81			
First rains (4.5 MAP)	1.45	4.2	2.4
Last rains (10.5 MAP)	3.9	7.9	16
Subsequent dry season (14 MAP)	nd	9.9	34
1981–82			
First rains (4 MAP)	1.51	2.7	0.67

[a]MAP = months after planting; nd = not determined.

Table 2. Establishment of cassava (TMS 30572) planted in the middle of the dry season, 1981–82, in relation to water and aldrin treatments and storage of planting material.

Treatment	Stand (% at 34 days after planting)	
	Fresh stakes	Stored stakes[a]
No water	32	38
500 mL water/plant	77	78
500 mL aqueous solution of aldrin (0.1% a.i.)/plant	85	72

[a]Cut from 2-m stakes stored vertically for 2 months on moist soil under shade.

Results

Planting at the commencement of the dry season resulted in satisfactory stands (97% in 1980–81 and 80% in 1981–82); plants grew slowly but continuously (Table 1) under the protection given by dimethoate sprayings. Mulched and unmulched plots afforded virtually identical crop growth. The growth of weeds, including *Euphorbia* sp. (which survived longest), had

Table 3. Establishment and height of cassava (TMS 30572) planted in the 1983 wet season, in relation to land preparation, mulching, and planting angle.

	Tilled		Untilled	
	Mulched	Unmulched	Mulched	Unmulched
Establishment (% at 19 days after planting)				
Vertical	100	97	95	98
Slanted	97	98	89	98
Horizontal	95	97	89	94
Height (cm at 68 days)				
Vertical	89	60	48	55
Slanted	86	55	43	48
Horizontal	66	52	24	48

ceased after 3 months of the dry season, whereas the cassava continued to grow.

When the rains resumed, the canopy already had an LAI of about 1.5, which afforded appreciable soil protection against raindrop impact. The canopy increased rapidly after the rains began, and it gave complete soil coverage within a few weeks. The numbers and yield of storage roots continued to increase through the wet season and also into the subsequent dry season (Table 1), although canopy depletion by pests commenced at 13.5 MAP in the second dry season, because dimethoate application was not resumed.

The supply of a single dose of water to both fresh and stored cassava stakes planted in extremely dry conditions (Table 2) produced a commercially satisfactory degree of establishment. Watered plants had enough resistance to termites, which destroyed many unwatered stakes, to obviate the need for insecticide applications. This experiment showed that a certain amount of soil moisture is needed for cassava establishment; dry-season planting should, therefore, be as soon as possible after the last rains. Once established, young cassava plants can survive desiccated conditions.

The plant establishment in the wet season under all the soil treatments was satisfactory and was achieved rapidly (Table 3). Horizontal planting produced lower plant height than did the other orientations because shoot initiation was closer to the ground. This finding suggests that cassava from stakes planted horizontally will be at a disadvantage in competing with weeds. The different degrees of contact between the planting material and the soil at different planting orientations and tillage treatments did not affect

Table 4. Vertical force required, yield lifted, and yield left in ground when mature plants (means of TMS 30572 and TMS 30211) were pulled up at different soil moistures.

	Before rain	After rain	After heavy rain
Vertical force (N)	740 ± 70	560 ± 40	630 ± 40
Soil moisture (g/100 g)			
0–10 cm	1.5	7.5	9.7
10–20 cm	2.4	7.8	7.0
Soil penetrometer resistance (MPa)			
0 cm	1.5	0.3	0.19
10 cm	4.6	1.8	2.0
20 cm	5.3	5.0	4.4
Yield (kg/plant)			
Lifted	4.0	3.6	4.3
Left	0.56	0.41	0.62

Table 5. Vegetative growth, relative amounts of soil splashed, and soil slumping for *D. alata* (TDa 297) planted in the 1983 wet season, in relation to land preparation and mulching.

Treatment	Time to 50% emergence (days)	Vine length (cm)[a]	Relative soil splash	Drop in soil surface (mm)
Untilled	33	280a	1.0	4
Plowed	30	329a	1.1	4
Plowed, mulched	33	304a	0.06	0
Plowed, ridged	37	277a	1.2	30b
Plowed, mounded	46	215b	1.0	39b

[a]Values not followed by the same letter are significantly different at $P < 0.05$.
[b]Soil slumping was measured half way to the top of the ridge or mound.

plant establishment or growth rates. Planting stakes on a slant may be preferred, however, because it is the easiest.

Soil splash, which is the first stage in sheet erosion (Hudson 1974) on tilled land, was 0.34 and 2.3 for mulched and unmulched plots and, on untilled land, was 0.34 and 1.0 for mulched and unmulched plots. In other words, the mulch used in this experiment reduced soil splash by 66% relative to bare undisturbed soil, and tillage, without mulch, more than doubled the splash, compared with the same standard. Thus, it seems unnecessary in this soil to resort to zero tillage for erosion control as long as there is full groundcover.

The five-fold variation in soil strength at the soil surface and three-fold variation at 10 cm deep at harvest only affected the force required for lifting by 25% (Table 4). Therefore, the difficulty in harvesting, which has been observed elsewhere in hard-soil conditions, appears to be caused by some factor other than hardness of the soil. Perhaps the depth of the roots or the strength of attachment of the roots to the soil is responsible.

In the yam experiment, mounding clearly delayed emergence and reduced vine growth (Table 5) — a finding that probably reflects the high soil temperature and low soil moisture in this treatment (data not presented). Soil splash was similar for all treatments except the one with mulching, which reduced splash to 6% of that on bare, undisturbed soil. The drop in soil-surface level caused by soil slumping and erosion was far greater on ridged or mounded plots than on flat treatments. Slumping leads to denser, packed soil, which offsets the benefits of loosening the soil brought about by ridging or mounding. Mulching not only ensured that the soil did not increase in density but actually improved the soil density by providing a suitable environment for prolific earthworm casting. In fact, the soil density was improved in all the experiments that included mulching.

Conclusions

Several of the advantages of dry-season planting of cassava have been reported previously (Vine and Obigbesan 1982), but our experiments have highlighted additional findings, primarily the increased yield from the mature crop and the need for some residual soil moisture for establishment. The early canopy closure after the start of rains helped considerably in weed suppression and soil protection. It was also found that drought for the first 4.5 months of growth did not adversely affect later increase in storage-root number.

In the conditions prevailing in the experiment reported, provision of full groundcover by crop residues, on tilled soil, may be substituted for zero-tillage practices for soil-erosion control. Bare, tilled soil is clearly undesirable. The experiment needs to be repeated over successive years to test the long-term applicability of these conclusions. More work also needs to be done to discover which soil factors determine ease of harvesting.

From the experiment with yam, it is clear that the whole field must be covered at all times in the wet season if erosion is to be moderated. Before canopy closure, groundcover must be achieved by mulch. In *D. alata*, ridges and mounds are suitable only where the water table is very high (Kowal and Stockinger 1973). The effect of soil treatment on tuber shape in the experiment remains to be determined, but tubers were seen to be lifting the soil in this experiment, perhaps achieving acceptable tuber expansion and shape.

FACTORS LIMITING CASSAVA PRODUCTION AMONG PEASANTS IN LUKANGU, ZAIRE

KILUMBA NDAYI[1]

A survey of cassava production was conducted in Lukangu, Zaire, in 1982. The study covered the type of land selected for cultivation; planting times; diseases, insects, and pests attacking cassava; the possibility of solving food shortages in the region by intercropping; and, lastly, the possibility of enabling the peasants to plant cassava in fertile valleys as a result of introducing improved resistant PRONAM varieties.

In 1982, a week-long survey was conducted on the cassava-production system adopted at Lukangu (Bakwa Lonji), 60 km from the Gandajika PRONAM station. Seven hundred peasants were interviewed and 150 fields observed. The purpose of the survey was to determine and define factors contributing to the depressed production of cassava, the staple food in the Katanda district. Results will be the basis of a program of agronomic trials and varietal studies and will provide objectives to be reached through extension work and distribution of improved PRONAM varieties of cassava.

Lukangu (Bakwa Lonji) is located in the Baluba Lubilanji collectivity, Katanda district, Tshilenge subregion in Kosai Oriental.

It is mountainous, with small valleys. In general, the soil is sandy, vegetation consisting primarily of *Hyparrhenia* spp. and *Andropogon* spp. Alluvial soil is found in the valleys. The climate is characterized by a rainy season beginning in August–September and ending in May with maximum rainfall in November (280.5 mm) and April (222 mm).

SYSTEM OF CULTIVATION

Cassava (October–December and February–March), maize (September–October and January–February), and beans (September–October and February–March) are the main food crops. Cotton growing (December–January) has been imposed and heads the rotation sequence recommended by the agriculture service. Groundnuts (September–October and February–March) are grown over a small area. Intercropping is universal among peasants in the region, and although the government is calling for cotton as a monoculture, smallholders plant cassava under the cotton when the latter is fruiting.

Two distinct rotation systems are used: in the non-cotton-growing area, a maize–bean intercrop heads the sequence beginning in September. Some farmers plant cassava as a relay crop under a mixed maize–bean crop, which is cut back in February–March to clear the ground for a second-season planting of maize (February–March). In the cotton-growing belt, the sequence begins with cotton, generally planted 25 December–15 January, depending on the short dry season (15 January–15 February). The cotton is followed by a mixed maize–bean or maize–cassava crop, then cassava, which is always last in the sequence (Table 1).

EFFECTS OF *XANTHOMONAS MANIHOTIS*

Preliminary survey results show that, when *Xanthomonas*-induced blight emerged, the farmers eliminated the susceptible cultivars, i.e., Kaladi, Kazeba, and Kasouga, which amounted to 75% of those they had been planting. Only Kakwanga, a late and bitter cultivar, proved blight resistant. The farmers introduced four new cultivars (Ndunda, Bon Marché 5097, Mutshi mukunze, and Mutshi mutoka) they believed to be resistant.

The newly introduced cultivars probably were

[1] Programme national manioc (PRONAM), Gandajika, Zaire.

Table 1. Crop rotation practices at Lukangu (1982).

	Intercrop
Non-cotton-growing area	
Sep.	Maize–beans
Nov.–Dec.	Cassava under maize
Jan.–Feb.	Maize–beans or maize under cutback cassava
Mar.–Apr.	Cassava under maize
Cotton-growing area	
Dec.–Jan.	Cotton
Sep.–Oct.	Maize–cassava
Jan.–Feb.	Maize–beans
Mar.–Apr.	Cassava

selected by farmers in a region where the inoculum caused little damage, as was the case with cultivar 5097 when the Commission agricole du Kasou-oriental (CAKO) was responsible for improving production (before PRONAM).

Planting

Cassava is planted in October and November 45–60 days after maize. It is intercropped with maize–beans, but the small percentage (4.76) of fields planted with cassava shows that most farmers prefer to plant a maize–bean intercrop at the beginning of the rainy season and cassava later (December–January) when they harvest the beans and weed the fields for a second planting of maize. At the same time, the farmers must prepare the land and plant cotton. The demands on labour peak at this time — the reason that only a small area is planted with cassava compared to the first and last growing periods (Table 1).

The last growing period begins March–April. Virtually half (49.62%) of the peasants in the region plant cassava at this time. The plant receives only 2 months' rain before 4 dry months. During the dry period, the crop is attacked by the green mite and is cut back at the beginning of the rainy season in September for planting under maize. Two months after resumption of the rainy season, cassava is attacked by bacterial blight and anthracnose, with the prevalence of blight peaking in January. The farmers (90%) stated that the disease was worse in the valleys than on the plateaus and hillsides. As a result, cassava is cultivated on the plateaus.

Results and Conclusions

Soil at Lukangu proved to be largely shaly sand. The clayey soils of the valleys are not being exploited for cassava production because of the severity of attack by *X. manihotis*. Cassava is generally planted on the plateaus or hillsides, near the valleys, in nitrogen- and phosphorus-poor soils.

As a result of the poor moisture retention of the soil and the prolonged dry season, the green spider mite seriously depresses root and leaf production. Thus, the fields planted with cassava are too small to tide the farmers over during the difficult period (August–December).

The cassava cultivars were susceptible to mosaic, bacterial blight, anthracnose, and *Mononychellus* spp. The exception was Kakwanga, which was tolerant to bacterial blight but late and very bitter, occasionally causing the fatal disease known as Kaswabanga during the period when maize is in short supply.

The introduction of resistant cassava varieties developed by PRONAM will enable the farmers to plant the crop in fertile valleys. Today, none of the farmers in the region have spare cassava fields. Consequently, there is no longer any validity in the recommendation, born in colonial days when cassava cropping was widespread but yields were poor, to plant in March–April.

Proper mixed cropping or intercropping (maize–cassava–beans) instead of maize monocrops that are imposed for the first growing season should help to eliminate food shortages in the region, especially as the peasants are unable at present to cope with the water problem, one of the chief constraints in increasing maize production despite the use of improved seed and chemical fertilizers.

EPIDEMIOLOGY OF ANTHRACNOSE IN CASSAVA

C. MAKAMBILA[1]

I studied the symptoms of anthracnose induced by *Colletotrichum manihotis* (*C. gloeosporioides*) on cassava plant stems. The symptoms develop on tissue that has become necrotic because of insect (*Pseudotherapus devastans*) bites and becomes the germination site for conidia from the pathogenic agent. The conidia produce a mycelium that subsequently propagates in the host tissues. I investigated factors, such as relative humidity, the type of insect-caused injury, insect populations, and stem lignification, to determine their effect on disease development. The study was conducted with either stem fragments or whole plants artificially inoculated.

Symptoms of anthracnose on cassava stems.

Of the many fungal diseases occurring in the cassava-producing belts of the Congo, in particular, and Africa, in general, *Colletotrichum gloeosporioides*-induced anthracnose of cassava is one of the most widespread (Chevaugeon 1956; Terry et al. 1976; Makambila 1978). The pathogen produces slightly rounded oval or elongated necrotic spots on the nonlignified portions of the stem. The agent becomes established in two stages. In the first, the plant is conditioned by the insect *Pseudotherapus devastans*, family Coreidae, which, by means of a sting, produces a tiny circular or oval necrotic spot with injury to the surface epidermal cells.

The second stage does not occur unless conidia germinate at the necrotic site and infect the stem tissues. Artificial inoculations in some cassava varieties have demonstrated that both stages are required (Makambila 1982). In other words, for anthracnose symptoms to develop in the cassava plant, injury-, insect-, and plant-related factors are needed. By artificially inoculating cassava stems with *C. gloeosporioides*, I was able to define the role of these factors, which include the type and age of the injury, the levels of humidity, the presence of *P. devastans*, lignification of the stem, and the presence of the pathogenic agent.

MATERIALS AND METHODS

Six local cassava varieties were selected for the study. In each variety, I inoculated either whole 3-month-old plants grown in pots, 200-mm-long stem fragments taken from nonlignified stems, or small, 70-mm-long fragments from stems that were not yet lignified or were undergoing lignification (Fig. 1).

The injury was produced by one of two methods: the stem was either pricked with a fine needle or simply placed in contact with *P. devastans* in a closed plexiglass container (height 220 mm, diameter 115 mm).

The inoculum was supplied in the form of a pellet (diameter 4 mm) containing mycelial fila-

[1] Département de biologie et physiologie végétales, Faculté des sciences, Brazzaville, People's Republic of Congo.

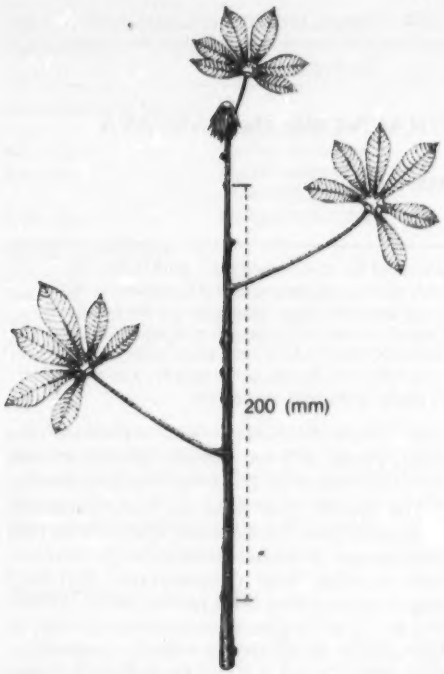

Fig. 1. *Stem portion of 3-month-old plants used in treatments.*

ments and conidia from a culture of *C. gloeosporioides* isolated from the cassava plant, incubated in the dark at 26°C and maintained in a culture medium containing 10 g/L malt and 14 g/L agar.

Inoculation consisted of placing inoculum on intact stems; on the sites injured by a fine, heated needle or insect sting; or on sites injured with a cold needle.

Following inoculation, the stems or whole plants were enclosed in transparent plexiglass containers (diameter 115 mm; height 220 mm) equipped with lids containing sterilized absorbent cotton soaked in sterile water to maintain the relative humidity at 90%. Another group of stems and plants with inoculum on sites injured by hot needle or insect sting were placed in identical, but open, containers. Hygrometric readings in these containers indicated 30–40% relative humidity. The containers with stems were incubated in the dark at 26°C for 6 days; the whole plants were placed on a laboratory bench.

Results

Results elucidated the role of the various factors involved in the development of anthracnose symptoms in cassava.

The type and age of the injury were studied. Placing inoculum on stems or plants injured by a hot needle or *P. devastans* produced brownish elongate or oval necrotic spots that were covered with yellow acervuli. These necrotic areas resembled symptoms observed in anthracnose-infected fields. The symptoms for stems or plants injured by a cold-needle puncture differed: slight darkening of the stem around the inoculation site but the pathogen was unable to progress further. Necrosis did not develop on stems that I inoculated 2 days after hot-needle puncture nor on stems inoculated 6 days after injury by *P. devastans*.

Necrosis was exacerbated at high (90%) relative humidity in the closed container, with a continuous longitudinal progression of the pathogen on stem tissues. When the relative humidity was low (30–40% in the open containers), on the other hand, the longitudinal progression of the pathogenic agent was slow and rapidly blocked.

To pinpoint the effect of humidity on the development of symptoms in cassava fields, I

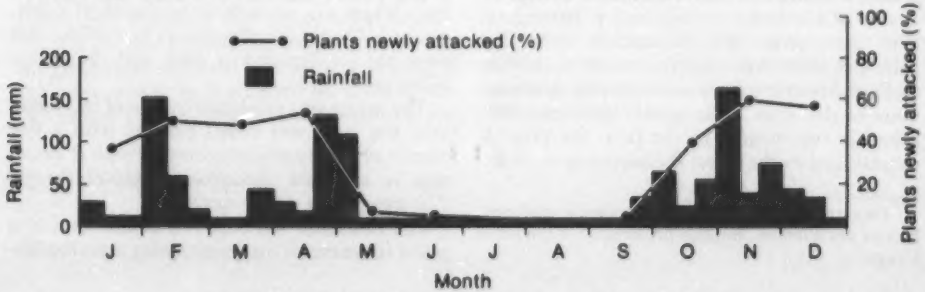

Fig. 2. *Newly attacked plants as a function of time and rainfall.*

Table 1. *Pseudotherapus devastans* activity: number of insect bites in 24, 48, and 72 h.

Insect	Time (h)		
	24	48	72
1	9	15	23
2	4	9	12
3	11	23	32
4	2	6	15

counted the number of plants with new lesions in an experimental field at Odziba on the 18th of each month from January to December. The percentage of new infections was high during the rainy months from January to April and again from October to December. The percentage dropped sharply during the dry season (Fig. 2).

Three factors related to the insect vector (*P. devastans*) were studied. The presence of an insect causing injury to the cassava stem is essential, as uninjured plants fail to develop symptoms. *Pseudotherapus devastans*' activity was also studied. Three 200-mm-long cassava stems were placed in each of 10 containers. One *P. devastans* insect was then introduced into each container. The numbers of insect bites were then counted after 24, 48, and 72 h. The results (Table 1) showed no pattern for insect activity.

The number of plants attacked by *P. devastans* depends on the size of the insect population. In five different localities in the Pool area, where *P. devastans* populations differ in size, the percentage of plants infected with anthracnose at Mbe and Odziba with dense *P. devastans*' populations was higher than in the other localities (Fig. 3).

Plant-related factors, i.e., sensitivity to *P. devastans* stings and to the pathogen and effect of lignification at the site of inoculation, were also investigated.

For the former, stems from various local varieties of cassava were placed in plexiglass containers into which *P. devastans* were later introduced. Insect stings on every stem produced necrotic areas that were subsequently measured (length, width, diameter). Results dif-

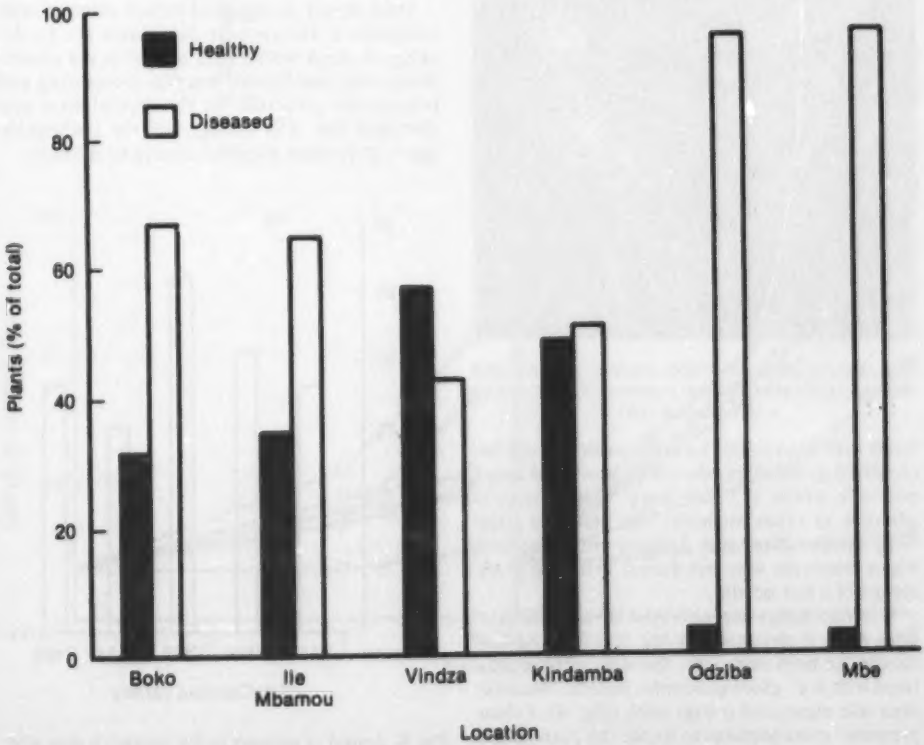

Fig. 3. *Plants attacked as a function of location and, hence, insect population.*

The cassava stem develops necrosis (NEC) and chancres (CH) after artificial puncture (P) and contact with inoculum (IN).

fered with the variety. In varieties that could be classified as sensitive, the stings produced large necrotic areas (13 mm long, 7 mm wide), whereas in other varieties, the necrotic sites were smaller. The same findings were recorded when necrosis was produced artificially by means of a hot needle.

Necrotic tissue was obtained by either insect bites from *P. devastans* or use of a fine red-hot needle. In both instances, the sites were inoculated with a *C. gloeosporioides* isolate. Necrotic area was measured 6 days later (Fig. 4). I then prepared cross sections to locate the pathogenic agent in the tissues.

The findings indicated that the speed at which the pathogen spreads differs with the variety and depends on sensitivity of variety to agent. The pathogen was either under the cuticle, in the epidermis, or within the vascular system, depending on the cassava variety.

I cut stems into fragments, 70 mm long, representing different degrees of lignification (Fig. 5). Each fragment was inoculated with a *C. gloeosporioides* isolate and placed in a plexiglass container with relative humidity kept high (90%). The necrotic areas were measured every day for 6 days. From the apex to the lower part of the stem (Fig. 5), the most pronounced anthracnose-related necrotic spots were located at an intermediate area where the stems had not yet completely lignified.

Discussion and Conclusions

The role and importance of various factors in the formation and development of anthracnose symptoms in cassava plants were determined.

Stem injury is required before contact with inoculum if anthracnose symptoms are to develop. A prick with a cold needle in my experiments was insufficient, whereas insect sting and hot-needle puncture at the inoculation site damaged the cells enough for the pathogenic agent to become established and to develop.

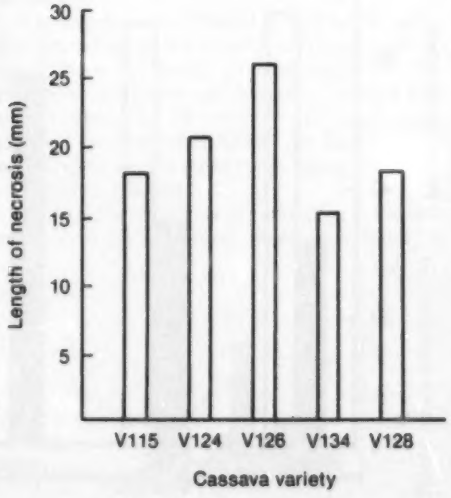

Fig. 4. *Length of necroses in five varieties 6 days after inoculation.*

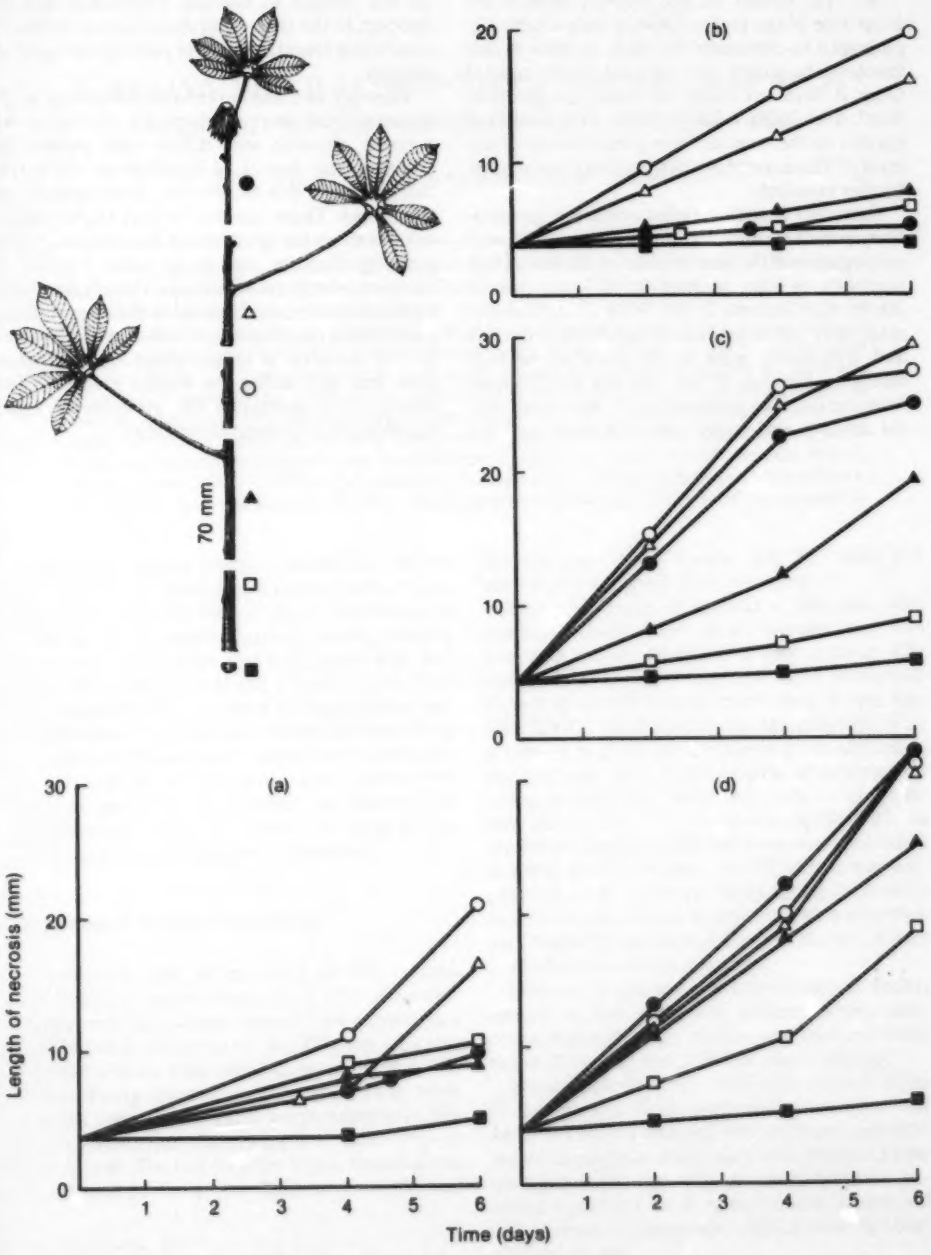

Fig. 5. *Length of necroses as a function of the portion of the stem, i.e., lignification.*

Yet, the results do not entirely explain the exact role of the injury. Does it only enable the pathogen to penetrate the stem or does it also favour subsequent propagation of the agent? Does it have any effect on conidium germination? And under what form does the conidium survive on the stem surface in the absence of any injury? These are some of the points that require further research.

Humidity is necessary for conidium germination, penetration of the pathogenic agent, and propagation in the plant tissues of the host. High humidity is also needed by *C. graminicola* (Sinha and Sharma 1973). With *C. coffeanum*, artificially obtained lesions sporulated quickly and continually grew in the presence of high humidity (Steiner 1974), and my observations were similar. The presence of *P. devastans*, vector activity, and population size were required for the disease to become established and to develop. In the absence of these factors, anthracnose is not found even if the pathogenic agent is present.

Varieties of cassava respond differently to *P. devastans* and, secondarily, to the pathogen. As a result, necrotic area differs with variety. In addition, the degree of lignification along the cassava stem conditions the development of symptoms. There are no, or only slight, symptoms at the stem apex, which has not yet undergone lignification, and at the lower portion of the stem where the tissues are already lignified. Optimal necrosis is observed in the intermediate zone where lignification is under way. This portion of the stem is longer when lignification is slow and the nodes are widely spaced. Conversely, it is shorter in the presence of rapid lignification and short internodes.

CASSAVA YIELD LOSSES FROM BROWN LEAF SPOT INDUCED BY *CERCOSPORIDIUM HENNINGSII*

J.M. TERI, P.W. MTAKWA, AND D. MSHANA[1]

We studied progress of cassava brown leaf spot (BLS) and its effect on yield of five cassava cultivars: Aipin Valenca, F279, Mzungu, Tanga, and T27. Field plots of each cultivar were established in an area where BLS is endemic, and half the plots were sprayed with the fungicide benomyl. We recorded disease progress in the plots by counting the number of lesions per plant and by recording percent defoliation. Disease intensity was highest between 3 and 6 months after planting. In 1981–82, the epiphytotic reached a peak 3 months after planting; in 1982–83, there was a low peak 3 months after planting and a higher peak at 5 months. All variables were subjected to analysis of variance with Duncan's new multiple-range test. The independent t-test showed very highly significant differences between sprayed and unsprayed plots. Root yield from fungicide-sprayed plots was compared with that from corresponding diseased plots, the differences in 1981–82 ranging from 1.7% to 32.3% for the four cultivars and averaging 26.8% for the susceptible cultivars. In 1982–83, the range was from 15.2% to 38.1% for three cultivars and 30% for the two susceptible cultivars.

Of all the major diseases of cassava, brown leaf spot (BLS) caused by *Cercosporidium henningsii* has been the least studied. The disease is endemic in all cassava-growing areas, causing premature defoliation and reducing yields. Because BLS doesn't kill the plants, it has been overlooked by both growers and agricultural scientists. Only recently, has some work been done to elucidate the economic importance of the disease (CIAT 1976; Teri et al. 1980). During the 1981–82 and 1982–83 seasons, we studied the progress and effect of brown leaf spot at the university farm, Morogoro, Tanzania.

MATERIALS AND METHODS

Healthy stakes, 20 cm long, of five cassava cultivars — Aipin Valenca, F279, Mzungu, Tanga, and T27 — were dipped for 4 minutes in a mixture of Dithane M-45 (40 000 ppm a.i.) and malathion E.C. (300 ppm) (Lozano et al. 1977) before being planted on flat land. They were pushed into the ground perpendicularly for about two-thirds their length at a spacing of 1 m × 1 m. The soil was clay loam. Planting was on 18 and 19 February 1981 and on 27 and 28 February 1982. Mzungu and T27 were not included in the 1982–83 experiment.

The experiment design was a split plot, with cultivars in the main plots. Subplot size was 5 m × 5 m with 36 plants of each cultivar. The fungicide benomyl (Benlate 50 WP), previously shown to be efficient in controlling brown leaf spot (CIAT 1976), was used at the rate of 0.75 kg a.i./ha in half the plots. Spraying was started at the first sign of BLS (1.5 months after planting) and continued at 2-week intervals — 15 sprayings during 1981–82 and 11 during 1982–83. In the other plots, natural infection was allowed to develop in 1981–82 and, in 1982–83, it was supplemented by artificial inoculation. All plots were kept free of insects and mites with dimethoate (Rogor E), sprayed at the rate of 1.0–1.5 mL/L of water at 4-week intervals.

Disease progress was assessed every 2 weeks: lesions on five randomly selected plants were counted per plot; defoliation was assessed three times (150, 180, and 210 days after planting).

Both experiments were harvested after 12 months and yield components recorded. All variables were averaged over cultivars and subjected to analysis of variance with Duncan's new multiple-range test. Significant differences between variables from sprayed and unsprayed (BLS-infected) plots were determined by independent t-tests.

As a measure of root loss caused by BLS,

[1] University of Dar es Salaam, Chuo Kikuu, Morogoro, Tanzania.

yields from 16 plants of fungicide-sprayed plots were compared with those from the same cultivar in unsprayed (infected) plots. Root length and diameter were measured for five randomly selected roots per plot. The number of roots per plot was divided by the number of plants as an estimate of roots/plant. Dry-matter content was determined from oven-dried samples. Harvest index was also determined.

Results

No other cassava disease occurred in the experimental area, and the fungicide effectively controlled BLS in the sprayed plots. There were highly significant differences in disease between sprayed and unsprayed plots in both seasons from 90 to 202 days after planting (DAP) (Fig. 1). The cultivar–spraying interaction was significant at every disease assessment in the 1981–82 season but was variable in 1982–83. The cultivars in order of increasing susceptibility were Tanga, T27, Mzungu, F279, and Aipin Valenca (Fig. 2). Disease intensity was highest between 3 and 6 months after planting, with the peak at 3 months for both years.

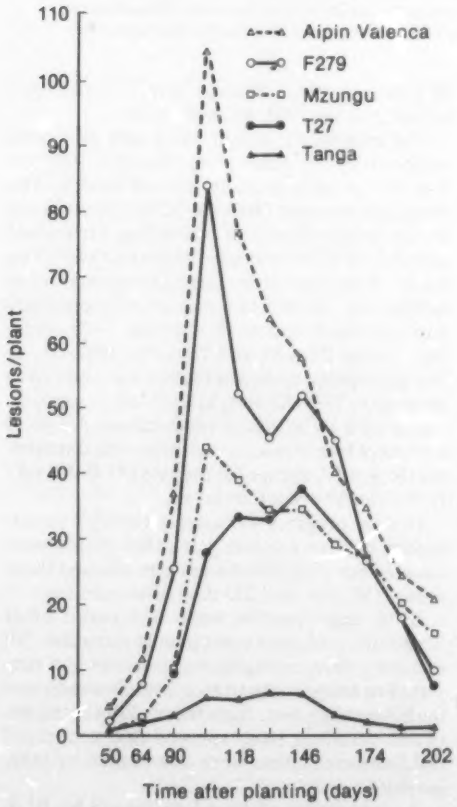

Fig. 1. *Progress of brown leaf spot (BLS) in five cassava cultivars not sprayed against BLS during 1981–82, Morogoro, Tanzania.*

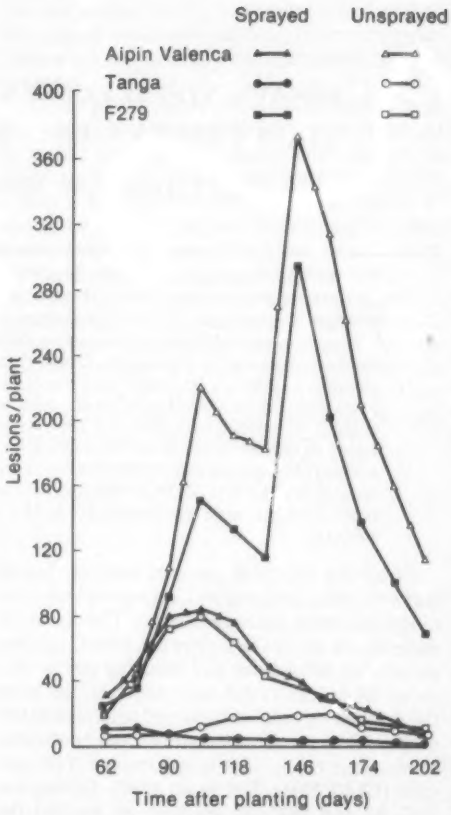

Fig. 2. *Progress of brown leaf spot in three cassava cultivars sprayed and unsprayed against BLS during 1982–83, Morogoro, Tanzania.*

Differences in defoliation between treatments were very highly significant in both seasons, but, toward harvest time, the differences between sprayed and unsprayed plots had disappeared. During the 1981–82 season, cultivar–spraying interaction was very highly significant during the three times that defoliation was assessed. In the 1982–83 season, the interaction was significant only at 210 DAP.

Table 1. Yield variables and percentage change for plots infected with brown leaf spot (BLS) compared with uninfected (fungicide-sprayed) plots during 1981–82 and 1982–83, Morogoro, Tanzania.[a]

	1981–82		1982–83	
	BLS-infected plots	% change from uninfected plots	BLS-infected plots	% change from uninfected plots
Root yield (fresh, t/ha)				
Total	14.7	−15.5**	26.3	−25.0***
Marketable	13.3	−14.7*	25.0	−26.3***
Root				
Number/plant	4.0	−13.0*	6.5	−19.4*
Length (cm)	40.2	− 3.8	31.0	− 6.7*
Diameter (cm)	4.8	11.6***	4.7	− 6.4
Dry-matter content (%)	38.2	0.8	37.2	− 1.0
Harvest index	0.5	− 2.0	0.6	− 2.5

[a]Significance levels: * = $P < 0.1$; ** = $P < 0.05$; *** = $P < 0.01$.

Table 2. Marketable yield of cassava roots from plots infected with brown leaf spot (BLS) compared with uninfected (fungicide-sprayed) plots during 1981–82 and 1982–83, Morogoro, Tanzania.[a]

	1981–82		1982–83	
	Mean yield from infected plot (t/ha)	% change from uninfected plots	Mean yield from infected plot (t/ha)	% change from uninfected plots
F279	17.5	− 1.7	26.2	−38.1***
Tanga	15.2	−15.6	29.4	−15.2
Aipin Valenca	16.0	−21.2*	19.6	−21.9
T27	4.4	−32.3*	—	—

[a]Significance levels: * = $P < 0.1$; ** = $P < 0.05$; *** = $P < 0.01$.

There were significant differences between treatments in total root yield, marketable (diameter 2.5 cm in the middle) root yield, and roots/plant (Table 1). Differences in dry-matter content of roots and in harvest index were not significant. Root length was significantly reduced by BLS only during 1982–83, and root diameter was significantly larger in the BLS plots during 1981–82 (Table 2).

Discussion

BLS has generally been regarded as a minor disease of cassava despite its widespread occurrence and the severe premature defoliation it causes. This attitude arises largely from the lack of empirical data to show the extent of yield loss that can result from the disease (Teri et al. 1980). Results from this study show a significant yield loss (21.2%) in Aipin Valenca and 32.3% in T27 during 1981–82. Tanga was the only cultivar that showed resistance, with reductions of 15.6% and 15.2% during 1981–82 and 1982–83, respectively, which were not significant. Mzungu was destroyed before it could be harvested.

These findings corroborate earlier reports (CIAT 1976; Teri et al. 1980) that BLS can reduce cassava yields significantly in susceptible cultivars. These results suggest a need for controlling BLS.

We are grateful to the International Foundation for Science (IFS), Stockholm, Sweden, for provision of funds for this work.

SUSCEPTIBILITY OF CASSAVA TO *COLLETOTRICHUM MANIHOTIS*

MUIMBA-KANKOLONGO A.,[1] M.O. ADENIJI,[2] AND E.R. TERRY[3]

Studies were conducted to determine how inoculum concentration, pathogen virulence, cassava host, insect mediation, planting time, and location influence the susceptibility of cassava to anthracnose. The results indicated that the severity of infection is directly related to inoculum concentration and virulence of the isolate, although no specific races were identified among the isolates. A latent phase of *Colletotrichum manihotis* exists, during which its acervuli can be recovered from tender, symptomless stems. *Pseudotherapus devastans* feeding on cassava mediate the initiation of infection, and the degree of infection varies according to planting season and location.

Although anthracnose development and the establishment of its causal agent (*Colletotrichum manihotis*) have been associated with environmental factors (Chevaugeon 1956; Lozano and Booth 1974), the factors contributing to sudden outbreaks of the disease are poorly understood. This paper gives results of several studies of these factors and their influence on the susceptibility of cassava to anthracnose.

MATERIALS AND METHODS

For studies of the effect of inoculum concentration, 7-week-old plants (clones TMS 70775, TMS 63385, and TMS 30001) were sprayed until runoff with spore suspensions of a 7-day-old culture of OW37 isolate containing 0.5×10^3, 1.5×10^4, 4.5×10^5, and 1.5×10^6 spores/mL. In each suspension, including the control, a drop of Tween-80 was added as a wetting agent. The plants were covered with moist, plastic bags to increase humidity and then maintained for 72 h in a controlled environment chamber (26–31°C, 60–80% relative humidity). Defoliation was monitored at 4-day intervals for 20 days.

For studies on the virulence of the causal agent, 28 isolates were collected from different parts of Nigeria. At 1 month old, plants were inoculated with 7-day-old colonies of each isolate by stem puncture at four places in the internodal areas. The inoculation was made with a hot needle, and the length of cankers recorded 10, 20, and 25 days after inoculation.

The possibility of a latent phase of *C. manihotis* on symptomless cassava stems was also investigated. Tender, symptomless tops from 6-month-old plants of 40 cassava genotypes were cut into four small segments (6 cm long) and washed thoroughly in running tapwater. They were surface-sterilized for 5 minutes in 95% ethanol; rinsed in three changes of sterile, distilled water; and allowed to dry for 1 minute. Each segment was maintained at 27–30°C and 68–85% relative humidity in petri dishes containing moist filter paper. When the stem tissues collapsed, they were observed under a stereoscopic microscope for the presence of acervuli of *C. manihotis*. Log transformation of data was used for the analysis of variance.

A study of the biological association between *P. devastans* and *C. manihotis* was conducted. Plants of TMS 30001 were subjected to various treatments, including spray inoculation with conidial suspensions of isolate IITA 11; spray inoculation followed by feeding of *P. devastans*; feeding followed by inoculation; feeding alone; and no feeding and no inoculation (control). Feeding lasted 4 days (three insects/plant), and the inoculum was adjusted to 1×10^4 spores/mL with the hemocytometer. Data on canker formation and size as well as plant death were recorded.

[1] Programme national manioc (PRONAM), Kinshasa, Zaire.

[2] Department of Agriculture — Biology, University of Ibadan, Nigeria.

[3] International Institute of Tropical Agriculture, Ibadan, Nigeria.

The reaction of four cassava genotypes (15, 21, 44, and 52) to anthracnose after natural infection was studied for two successive seasons (wet and dry seasons) at four locations (block CS8, C7, C6, and CS4) within the IITA farm. The score on a scale of 1–5 for disease severity was determined by the number of cankers per plant, with 1 representing no cankers and 5, more than 90. The number of cankers was recorded at 1-month intervals from the time that symptoms appeared until cankers coalesced to form tip dieback. The sum of scores for individual plants was divided by the number of plants multiplied by 5 and then expressed as a percentage — the infection index.

Results

The rate of defoliation increased with concentration of inoculum (Fig. 1). Defoliation was 95.8% on TMS 63385 sprayed with 4.5×10^5 spores/mL, whereas it was 17.8% on TMS 70775 sprayed with 0.5×10^3 spores/mL. The three clones did not differ significantly ($P < 0.05$), and none of the untreated plants lost leaves.

Virulence studies indicated that the isolates differed significantly ($P < 0.05$) in their ability to induce cankers (Table 1). Isolates Ib10, ON26, ON27, ON30, OW33, and OW37 were highly virulent on TMS 70775 as were Ab4, Ab25, ON26, ON27, and OW37 on TMS 30001.

Aj40 and IK46 were the least-virulent isolates on all three clones and ON26, OW33, and OW37 were among the most virulent. Clone TMS 70775 was more susceptible than either TMS 63385 or TMS 30001. There was no significant clone–isolate interaction.

The number of acervuli on stem segments of genotypes 2, 14, 29, 40, and 47 (mean log being 2.39, 2.21, 2.04, 1.93, and 2.11, respectively) was significantly higher ($P < 0.05$) than that on genotypes 8, 21, 25, 49, and 50, in which the number was 0.50, 0.58, 0.48, 0.48, and 0.40 respectively. Stem segments of genotypes 8, 15, 23, 27, 31, 32, 38, 44, and 51 did not produce acervuli of the fungus until the completion of the experiment.

After *P. devastans* fed on cassava plants, slight pale-green cankers developed, but there was no evidence of *C. manihotis* colonization. Following inoculation, the cankers rapidly spread along the point of puncture to about 15–20 mm apart. Their length varied with treatments (Table 2). The size (mean, 18 mm) of the cankers on plants in which feeding of *P. devastans* came before inoculation was larger than that for other treatments. About 98.7% of plants in the inoculation-plus-feeding treatment had died by the end of the test (Table 3).

Data indicated significant differences ($P < 0.05$) in the infection index between genotypes, locations, and seasons of planting (Table 3). The dry-season crop had a higher infection index than did the wet-season crop. Genotype 15 in field C7 during the dry season had the highest index (70.1%), with significantly

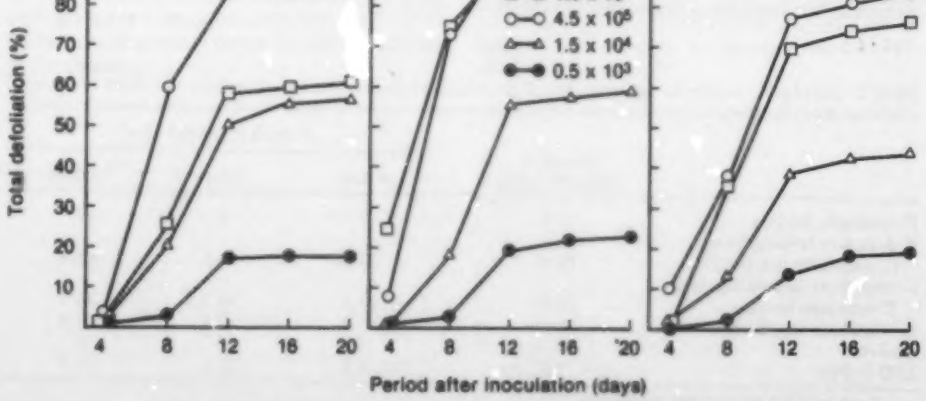

Fig. 1. *Effect of spore concentration on the defoliation of three cassava clones.*

Table 1. Length (mm) of lesions caused by 18 isolates of *Colletotrichum manihotis* on three cassava clones 10, 20, and 25 days after hot stem puncture inoculation.[a]

		TMS 70775			TMS 63385			TMS 30001		
Isolate	Source	10	20	25	10	20	25	10	20	25
Ab4	Ogun	6.0	6.7	6.9	7.3	7.7	8.4	5.9	6.4	6.7
IITA 5	Oyo	9.1	10.1	10.4	5.1	5.5	6.0	6.6	7.0	7.0
IITA 7	Oyo	7.5	8.3	8.3	5.7	6.2	7.2	5.5	5.9	6.2
Ib9	Oyo	6.3	6.9	7.2	6.3	7.3	7.6	6.0	6.2	7.3
Ib10	Oyo	8.9	14.5	15.9	8.4	8.9	10.0	5.6	6.3	6.7
IITA 11	Oyo	7.3	8.5	10.2	6.2	6.9	7.1	4.9	5.5	6.2
Ab12	Ogun	8.0	8.6	8.9	7.0	7.3	7.4	5.1	5.5	6.0
IITA 16	Oyo	9.4	10.4	10.7	6.0	6.6	7.0	5.8	6.2	6.4
IITA 17	Oyo	7.4	8.8	9.6	7.0	7.3	7.8	5.9	6.3	7.0
IITA 19	Oyo	4.0	5.4	6.0	4.5	4.7	5.2	6.0	6.9	7.0
Ab25	Ogun	7.3	11.0	11.3	7.3	7.9	8.1	7.4	7.9	8.2
ON26	Rivers	9.6	11.3	13.2	6.2	6.5	6.5	7.1	7.9	8.1
ON27	Rivers	12.2	14.5	15.7	5.6	6.7	7.1	6.6	7.9	8.0
ON30	Rivers	10.0	11.4	12.2	6.1	6.9	7.1	5.0	5.8	6.0
OW33	Imo	9.4	11.1	12.0	6.0	7.2	7.5	8.9	10.0	10.3
OW37	Imo	10.2	11.5	12.0	6.8	7.0	7.1	6.7	8.1	8.5
Aj40	Ondu	4.2	4.8	5.1	4.1	4.9	5.3	4.2	4.8	5.3
IK46	Ogun	4.1	5.4	6.4	3.9	4.7	4.8	4.4	5.3	5.5

[a]Each value is an average of 4 cankers/plant and 3 replications.

more cankers than any other treatment. The season × location × genotype interaction was not significant ($P < 0.05$).

Discussion and Conclusions

Infection increased with inoculum concentration up to a maximum with 4.5×10^5 spores/mL, decreasing again with the higher concentration of 1.5×10^6 spores/mL. This phenomenon has been interpreted by Van der Plank (1975) as inhibition of spore germination when the inoculum is abundant. The results suggest that the disease prevalence and severity will be greatest in a location where the pathogen is at its optimal concentration.

The invasion of wounded stems by the isolates always resulted in cankers, the severity depending on the clone and the isolate. *Colletotrichum manihotis* is a weak pathogen (Chevaugeon 1956) that invades weakened tissue. That there was no significant clone–isolate interaction showed a total absence of specific races among isolates, but the difference in the length of cankers indicated that the isolates differ in virulence.

Table 2. Effect of *C. manihotis* inoculum and *P. devastans* feeding on the size of cankers and death of cassava.

	Length of cankers[a] (mm)	% death of plants[b] after		
		4 days	8 days	12 days
P. devastans feeding	11.9	0	0	0
P. devastans feeding then *C. manihotis* inoculation	18.0	60.0	84.6	88.4
C. manihotis inoculation then *P. devastans* feeding	14.9	65.4	98.7	98.7
C. manihotis inoculation	0	0.8	2.9	2.9
Control	0	0	0	0
LSD (0.05)	2.8	4.2	23.8	21.7

[a]Each value is a mean of four replications.
[b]Percent mortality based on plants with tip dieback.

Table 3. Anthracnose infection index as influenced by location and season of planting.[a]

Location (block)	Genotype	Infection index (%)[b] Wet-season crop (month)[c] 1	2	3	4	Dry-season crop (month)[c] 1	2	3	4
CS8	21	40.0	45.0	47.5	47.5	20.0	40.0	43.3	47.5
	15	38.2	43.3	47.5	47.5	25.0	52.5	55.1	57.5
	52	29.1	44.6	44.8	50.0	29.5	57.8	62.7	62.7
	44	20.0	20.0	25.0	27.5	24.8	44.1	47.5	47.5
C7	21	37.5	37.5	37.5	40.0	20.0	40.0	42.5	47.5
	15	20.0	20.0	22.4	27.5	45.0	67.7	70.1	70.1
	52	20.0	35.6	37.4	39.8	34.7	52.5	52.5	52.5
	44	20.0	29.1	29.1	29.1	29.5	52.5	52.5	52.5
CS4	21	29.1	29.1	29.1	29.1	20.0	40.0	42.5	47.5
	15	20.0	20.0	20.0	20.0	20.0	62.7	62.7	62.7
	52	20.0	24.8	27.5	27.5	20.0	50.0	55.1	60.2
	44	20.0	20.0	20.0	20.0	27.5	47.5	47.5	47.5
C6	21	22.4	25.0	27.5	27.5	25.0	37.5	40.0	40.0
	15	20.0	20.0	20.0	20.0	27.5	60.2	62.7	62.7
	52	20.0	20.0	20.0	20.0	20.0	54.6	58.0	58.0
	44	20.0	20.0	20.0	20.0	29.9	44.9	47.5	47.5

[a]LSD (0.05) between seasons was 3.7; between locations 1.7; and within genotypes 0.85.
[b]Each value is a mean of two replications and 4 plants/genotype.
[c]Data were recorded monthly from symptom appearance to 4 months.

The death of stem tissues created a suitable environment for the development of *C. manihotis* acervuli, and the occurrence of acervuli on symptomless stems also shows that sporulating cankers are associated with latent infection, which could cause serious outbreaks of anthracnose within cassava plantations.

The inability of the inoculum alone to induce anthracnose cankers is evidence that more than one factor is involved in the development of the disease. Only in combination with *P. devastans*, did the inoculum produce acute infection. This finding supports the conclusion that *P. devastans* is the most important factor for the occurrence of the disease.

Because anthracnose is caused by the interaction of several factors, natural infection may occur when planting is delayed or it may be dormant until the conditions are more favourable. The analysis of variance showed that the interaction between genotype, location, and season was not significant. The significance of the findings is that factors influencing anthracnose vary between cropping periods and within different ecological areas.

We wish to thank Dr M.S. Ghauri for identification of insects, Dr J.E.M. Mordue for identification of fungi, and M.I. Owolabi for arranging the materials used in the experiments.

BOTRYODIPLODIA STEM ROT OF CASSAVA AND METHODS OF SELECTING VARIETIES FOR RESISTANCE

G.W. OTIM-NAPE[1]

After *Botryodiplodia* stem rot of cassava (CSR) was observed for the first time in Africa (in Uganda) in 1981, a series of experiments were initiated to determine the effects of stem maturation on infection; to identify suitable methods of screening for field resistance; and to screen varieties for sources of resistance to the disease. Four cassava varieties were planted in a split-plot experiment, with varieties as the main plots and heights as the subplots. At maturity, the stems were harvested, and the number of *B. theobromae* pustules counted. The number of pustules was directly related to maturity of the stem. Two methods of screening for resistance were compared: scoring for rot severity on a 0–5 scale and counting rot pustules per unit area. Scoring for severity was deemed most suitable for resistance screening, and counting of pustules had advantages for epidemiological and pathogenicity studies. In screening tests of eight families, four: IYT (OP) 1979; PYT (OP) 1980; 30555 (OP) 1979; and 30572 (OP) 1980 exhibited some resistance to the disease.

Cassava stem rot (CSR), caused by *Botryodiplodia theobromae* occurs in several Latin American countries (Lozano and Booth 1976) where it infects stored stem cuttings and debris in the field. Since 1981, CSR has been observed on cassava stems growing in the field. The symptoms start as small swellings or blisters on epidermal tissues of matured cassava stems. The blisters develop and rupture into pustules. In the pustules, some perithecia of *B. theobromae* can be detected. In the very young pustules, a dark brown stroma that produces perithecia progressively is sometimes visible under a microscope. On the epidermis beneath the pustules, internal infected tissues appear dark brown or black. The pustules can easily be mistaken as rust pustules if not carefully observed.

Since the confirmation of the disease, my colleagues and I at the Serere Agricultural Research Station have conducted studies of the infection to determine its relation to stem maturation; to develop a suitable method for assessing disease severity; and to identify cassava varieties and lines with resistance to the disease.

MATERIALS AND METHOD

In 1981–82, we examined two local (Bwanateraka, Bintiminti) and two improved (Bukalasa 8 and 11) cassava varieties. The experiment was a split-plot design, with cassava varieties as the main plots and stem maturation as the subplots. Plots were 7 m × 7 m, planted 15 October 1981 with cassava at 1 m × 1 m. Stems were harvested 12 months later. Stem maturation was gauged by height, within four groups: 0–60 cm; 61–120 cm; 121–180 cm; and 181–240 cm. At 1 year, 10 stems, approximately equal in size, were cut from each plot and divided into portions corresponding to the four heights. On each of the pieces, 10 areas 2.5 cm × 2.5 cm were marked, and the rot pustules within each area counted with the aid of a magnifying lens. Analysis of variance was done, as were correlation and linear-regression tests.

This method of assessing the severity of infection was effective but time-consuming. In an attempt to find a more convenient method, we assessed stem rot on a scale of 0–5, a modified Cobb scale (for cereal leaf and stem rust) (Peterson et al. 1948), with 0 for no rot pustules and 5 for overlapping, abundant pustules on rugose stems with dying lateral buds. We examined 80 stems of the four varieties using the two methods concurrently. Each variety consisted of 20 12-month-old cassava stems selected at random from the field. Correlation and linear-regression analyses were carried out.

In a third set of investigations to identify sources of resistance to stem rot, we assessed

[1] National Root Crops Improvement Programme, Serere Agricultural Research Station, Soroti, Uganda.

Table 1. Frequency (pustules/cm²) of CSR at 0–60, 61–120, 121–180, and 181–240 cm above ground on stems of four cassava varieties.[a]

Variety	0–60	61–120	121–180	181–240
Bukalasa 8	4.88(2.21)f	4.41(2.10)f	3.39(1.84)g	2.07(1.44)h
Bintiminti	4.84(2.20)f	4.04(2.01)f	3.13(1.77)g	2.40(1.55)g
Bwanateraka	4.75(2.18)f	4.24(2.07)f	3.35(1.83)g	2.13(1.46)h
Bukalasa 11	5.48(2.34)f	4.24(2.07)f	3.31(1.82)g	2.13(1.62)h

[a]Figures in parentheses refer to square-root transformation; figures within the same row or column followed by different letters differ significantly at the 5% level of probability.

open-pollinated (OP) seeds of eight families — 30572 1980; 30555 1979; 30395 1979; IYT 1979, PYT 1980; and AYT 1979, from the International Institute of Tropical Agriculture (IITA), and Bukalasa 8 and 11, our improved local varieties. They were planted 10 August 1981, 0.5 m × 0.5 m apart. The plants were allowed to develop stem rot naturally and were assessed at age 12 months.

Results

The rot pustules on the stems varied in colour and size according to variety. On Bukalasa 11 and Bintiminti, they were generally straw-coloured, whereas, on Bwanateraka and Bukalasa 8, they were dark brown and light brown, respectively. They were generally more abundant below leaf scars than elsewhere.

The four varieties did not differ significantly in number of rot pustules, although Bintiminti and Bwanateraka tended to have fewer pustules within the first 120 cm above ground than did the other two varieties (Table 1). Generally, pustules were fewer on the tops, or younger portions, of stems. Correlations between pustules/cm² and heights of stems were very highly significant ($P < 0.01$) (Fig. 1), and the 0–5 scale (Table 2) of increasing severity was correlated ($r = 0.56$) with the number of rot pustules. Seedlings of the cassava families from IITA generally performed better than did seedlings from the local varieties.

Discussion

The variations in colour of the rot pustules probably reflect differences in stem pigmentation. Like the pustules, stems of Bukalasa 11 and Bintiminti are straw-coloured when mature and those of Bwanateraka and Bukalasa 8 are dark brown and light brown, respectively.

The abundance of stem-rot pustules on parts of the stem immediately below leaf scars can be attributed to the fact that these parts usually hold slightly more moisture than do other parts of the stem. The moisture likely encourages disease development. The protrusions cushioning leaf scars may also protect the conidia from being blown away by wind.

The local varieties, Bwanateraka and Bintiminti, had fewer rot pustules and were, hence, more resistant than were the improved Bukalasa 8 and 11. This implies that the host has adapted somewhat to the pathogen and that the infection has been in Uganda for a long time. The fact that the disease is widespread in the country supports this view.

Young, green stems of cassava normally do not become infected by stem rot, probably be-

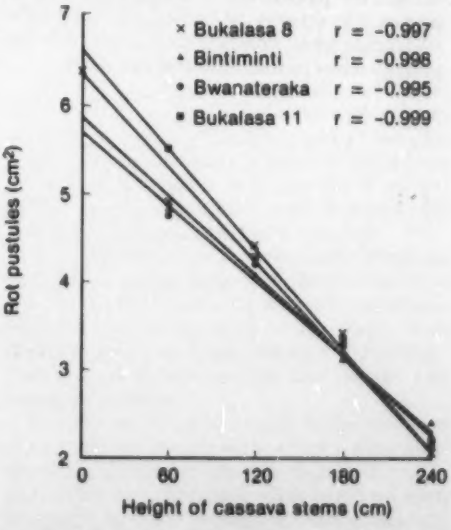

Fig. 1. *The effect of varieties and height of cassava stems above ground on infection frequency of cassava stem rot.*

Table 2. Severity scores[a] of seedlings from eight cassava families infected naturally by CSR.

	Seedlings tested	Score (% of seedlings)					
		0	1	2	3	4	5
IYT 1979	241	27	26	19	20	8	0
30395 1979	132	12	11	39	27	9	2
30572 1980	95	17	16	23	22	17	5
30555 1979	183	13	22	26	28	8	3
PYT 1980	181	17	38	24	21	0	0
AYT 1979	180	12	20	33	30	16	0
Bukalasa 8	143	10	21	24	28	14	3
Bukalasa 11	213	8	12	18	32	18	12

[a]0 — no rot pustules on mature stem; plant is immune; 1 — very few pustules; 2 — abundant pustules; 3 — crowded and abundant pustules; 4 — overlapping pustules on stems that are becoming rugose; 5 — overlapping of most pustules on completely rugose stems, withering and death of lateral buds, and occasional tip drying of lateral branches.

cause the cuticular layer remains intact. Inhibitory factors are also likely to be providing some protection. The cuticular layer normally becomes suberised as the stem matures and thus becomes liable to infection. These findings have important implications for screening varieties for rot resistance: only the first 0–120 cm of mature stems should be assessed for rot infection.

The close correlation of severity rating (0–5 scale) with number of rot pustules indicates that disease scoring can be used in screening, although the more precise method would be needed for pathogenicity and epidemiological studies. The severity rating is simple but may be misleading when infection level is very low, especially when pustules are few and large.

The use of varieties of cassava resistant to stem rot alone would be pointless because of the many other, more serious pests and diseases affecting the plant. In this study, resistance to rot was exhibited by cassava families developed at IITA for high resistance to bacterial blight and cassava mosaic disease.

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DISTRIBUTION AND SEVERITY OF CASSAVA MOSAIC IN THE CONGO

R. MASSALA[1]

Phytosanitary surveys in the People's Republic of Congo have shown that cassava mosaic disease (CMD) occurs throughout the country although the prevalence and effects of the disease differ with the ecological zone. Under the auspices of PRONAM (Programme national manioc), my colleagues and I are studying the prevalence and rate of natural infection of local and introduced varieties as well as other epidemiological factors. Identification and characterization of the causal agent of CMD are also planned.

Cassava mosaic disease in Africa is thought to be a virus of the geminivirus family, transmitted by whitefly, *Bemisia tabaci*. Mosaic modifies the structure of the plant, causes metabolic disorders, reduces the size and starch content of root cells, and means losses in yields that vary with the variety.

As part of the Programme national manioc (PRONAM) conducted under the auspices of the Conseil national de la recherche scientifique et technique (CNRST), my colleagues and I organized a study on the disease in the People's Republic of Congo.

Phytosanitary surveys have shown that the disease is found throughout the country but, from south to north, disease intensity ranges from 1 to 5, on the scale devised by G. Cours. In the scuth, in the forest area (Mayombe), the symptoms are mild, although intensity in some areas is as high as 3. In the middle of the country, in the savanna zone, the intensity is similar. In the northern part of the country, in the equatorial forest zone, symptom severity is as high as 5. In this area, the crop is grown almost exclusively in small peasant holdings, whereas, in the central part, some operations are large and mechanized.

All the observations made to date have shown that the disease occurs throughout the country. Symptom severity varies between regions and also between the groups of local varieties found in different regions. Although susceptibility to CMD varies, there is virtually no resistance to the disease.

Our future study under the conditions existing in the Congo will consist of:

- Identification and collection of healthy plants among existing local varieties;
- Survey of the prevalence and rate of natural infection of local varieties and varieties that have been introduced (from the International Institute of Tropical Agriculture, for instance);
- Attempts to reverse susceptibility by means of grafting stakes on infected cassava stalks;
- Examination of the ecological factors promoting or impeding the development of the disease; and
- Research on the correlation between the presence of *B. tabaci* and disease severity.

This epidemiological study will provide the data needed to determine whether a program to establish a reserve of healthy stock of varieties cultivated in the country is feasible under local conditions. Should the infection rate prove too high, then efforts will have to be devoted to the selection of "mosaic-resistant" varieties.

The regeneration of varieties from collections that are of interest because of their technical or nutritional characteristics warrants consideration. One way to do this is to take stakes from healthy plants or from diseased "reverting" plants; another way is to use heat therapy and meristem cultures.

It is important to plan a study on the pathogen responsible for mosaic in the Congo. Identification and characterization of the agent will enable us to compare it with pathogens that have been identified in other regions of Africa, namely, Kenya, Nigeria, and Ivory Coast.

[1] Département de biologie cellulaire et moléculaire, Université Marien Ngouabi, Brazzaville, People's Republic of Congo.

THE CASSAVA MEALYBUG FRONT HYPOTHESIS: ROLE OF INDIGENOUS NATURAL ENEMIES

K.M. LEMA,[1] R.D. HENNESSEY,[2] AND H.R. HERREN[1]

Ten years after the discovery of the cassava mealybug, *Phenacoccus manihoti*, in Zaire, reports claim that damage from the pest in Bas-Zaire and Bandundu states has been decreasing since 1978 and reached a minimum in 1983. At the same time, severe outbreaks have been reported in Kivu and Shaba states where the pest has recently been introduced. We believe that cassava mealybug infestations form a "front" that progresses to colonize and destroy new areas, whereas in previously invaded areas the damage is gradually reduced. This phenomenon and the role that might have been played by indigenous natural enemies as well as that of other factors are discussed in this paper.

Since its discovery in Zaire in 1973, the cassava mealybug, *Phenacoccus manihoti*, has spread to almost all cassava-growing areas of Africa. Ten years after the pest was discovered, farmers in Bas-Zaire and Bandundu, the first two states of Zaire to be invaded by the pest, are claiming that the severity and the extent of damage caused by *P. manihoti* have been reduced to almost nil.

A hypothesis has been developed to explain this phenomenon — the cassava mealybug front. According to this hypothesis, when the cassava mealybug invades a region, it causes extensive damage at first; then it forms a front that progresses to colonize and destroy new areas. After a few years, the front moves, and the damage in previously infested areas is drastically reduced. Indigenous natural enemies of the mealybug are being suggested as the main reason for the decline. In this paper, we discuss the hypothesis and the action of indigenous natural enemies as well as that of other factors that might contribute.

FACTS IN SUPPORT

There are no solid data (population or damage-level studies) to back up the claim, but some facts support it:

- A questionnaire was sent to several farmers in Bas-Zaire and Bandundu, and all farmers who responded confirmed that damage from mealybug, which started to decline after 1978, has reached an acceptable level;
- Farmers' fields were inspected, and no mealybug damage was observed, although a few mealybug colonies were found;
- Visits and field observations made in Bas-Zaire and Bandundu in late July 1983 (in Bas-Zaire and Bandundu, the dry season starts in the second half of May and ends in September) revealed that the usual bunched-top symptom was scarce (D. Perreaux, personal communication); and
- Severe outbreaks of cassava mealybug were recently reported in Kivu and Shaba states in Zaire, an indication of a progressing front. The pest is believed to have moved fairly recently (late 1970s early 1980s) into those two states.

POSSIBLE CAUSES OF DAMAGE REDUCTION

Many indigenous natural enemies have adopted the cassava mealybug as a host in several regions in Africa (Table 1). Their impact as biological control agents on the pest, however, has not yet been well documented. In Bas-Zaire, small cassava fields were freed from mealybug infestations by indigenous predators, mostly *Exochomus flavipes*. In Shaba, a small (about 0.10 ha) field heavily attacked by the mealybug was surprisingly free from mealybug attack within 3 weeks. This recovery reflected a combined action of *Exochomus* sp., *Hyperaspis* sp., *Spalgis*

[1] International Institute of Tropical Agriculture, Ibadan, Nigeria.

[2] Programme national manioc (PRONAM), Kinshasa, Zaire.

Table 1. Indigenous natural enemies of the cassava mealybug.

	Country	Reference
Parasitoids		
Encyrtidae		
Anagyrus spp.	Zaire	PRONAM 1978
	Congo	Fabres 1981
A. bugandensis	Zaire	PRONAM 1978
Predators		
Anthocoridae		
Cardiostethus exiquus	Congo	Matile-Ferrero 1977
	Zaire	PRONAM 1978
Cecidomyiidae		
Coccodiplosis citri	Congo	Fabres 1981
	Zaire	PRONAM 1978
Dicrodiplosis spp.	Congo	Matile-Ferrero 1977
	Zaire	PRONAM 1978
Leptodiplosis? aonidiellae	Congo	Matile-Ferrero 1977
Lycaenidae		
Spalgis lemolea	Congo	Matile-Ferrero 1977
	Zaire	PRONAM 1978
	Nigeria	K.M. Lema, unpublished
Geocoridae		
Geocoris amabilis	Nigeria	Akinlosotu 1982
Coccinellidae		
Chilocorus nigritus	Zaire	PRONAM 1978
C. angolensis	Zaire	PRONAM 1978
Cheilomenes lunata	Nigeria	Akinlosotu 1982
C. vicina	Nigeria	Akinlosotu 1982
C. sulphurea	Zaire	PRONAM 1978
Exochomus flavipes	Zaire	PRONAM 1978
	Nigeria	Akinlosotu 1982
E. concavus	Congo	Matile-Ferrero 1977
E. flaviventris	Congo	Matile-Ferrero 1977
Hyperaspis pumila	Nigeria	Akinlosotu 1982
H. senegalensis	Nigeria	Akinlosotu 1982
	Congo	Fabres 1981
	Zaire	PRONAM 1978
Lotis nigritula	Zaire	PRONAM 1978
Micraspie striata	Zaire	PRONAM 1978
Nephus sp.	Zaire	PRONAM 1978
N. derroni	Congo	Fabres 1981
Platynaspis sp.	Congo	Fabres 1981
P. vittigera	Zaire	PRONAM 1978
Serangium kunowi	Zaire	PRONAM 1981
S. giffardi	Congo	Fabres 1981
Scymnus spp.	Congo	Fabres 1981
	Nigeria	Akinlosotu 1982
S. rufifrous	Congo	Fabres 1981
S. plebejus	Congo	Fabres 1981
Pathogens		
Unidentified fungus	Nigeria	K.M. Lema, unpublished

lemolea, and larvae of a cecidomyiid fly, probably *Dicrodisplosis* sp. Umeh (1982), in Nigeria, reported that *Hyperaspis marmottani* drastically reduced mealybug infestations on a farm. Later, however, she had to abandon studies on this predator because of its delayed and lowered activity in subsequent observations (personal communication).

In the past, several introduced pests have become widespread (Greathead 1971) and have at-

tracted a large number of natural enemies. These natural enemies, however, have not achieved any satisfactory control (Doutt and Debach 1964; Parker 1970; Debach et al. 1971; Greathead 1971; Sailer 1974).

The coffee mealybug in Kenya, the pineapple scale and coconut scale in Mauritius (Greathead 1971), the Florida red scale in Israel (DeBach et al. 1971), and the imported cabbageworm in the USA (Parker 1970) attracted respectively 8, 2, 5, 1, and 12 indigenous natural enemies, but none of these pests was controlled by its local enemies.

Indigenous natural enemies of the mealybug are associated with moderate-to-high densities of the prey and become abundant only late in the dry season after appreciable damage has been done to the crop. This delayed action may be explained at least in part by the separation of the host, which is very scarce on cassava in the rainy season, and its local natural enemies, which are on weeds. Although coccinellid predators and some matings were observed on five weed species, including *Gassia mimosoides*, *Hibiscus* sp., *Tephrosia flexuosa*, *Urena lobata*, and a cultivated vegetable (*Hibiscus* sp.), we found no immature coccinellids in 2 years on these weeds or on cassava. A detailed study is under way to assess the behaviour and populations of the coccinellids on these weeds. In the 1982 rainy season, the population of *Hyperaspis senegalensis*, the most important predator of mealybug in Oyo and Ogun states of Nigeria, was studied on the weed *Hibiscus* sp. The monthly average numbers of adult *H. senegalensis* on this weed were 3.5, 3.3, 1.1, and 0.1 respectively for June, July, August, and September. Whole-plant counts were made twice every month to assess the predator population.

Along with natural enemies, climatic changes are known to affect insect survival, reproduction, feeding, etc. adversely (Uvarov 1931; Andrewartha and Birch 1954; Dempster 1975); in fact, Ehrlich et al. (1972) and Dempster (1975) reported some local insect populations have been eliminated by abnormal weather. Bas-Zaire was hit by a long drought in 1978 and widespread floods in 1981–83. Whether these changes reduced mealybug populations significantly is not known, but one of us (RDH) is compiling weather records to assess climatic changes in Zaire for the last 10 years.

The weather changes may have favoured the cassava green mite (*Mononychellus* sp.), which competes with the mealybug. In general, where damage from mealybug is reduced, the damage from green mite increases. The problem has been compounded recently, as green-mite infestations in the rainy season are becoming as important as in the dry season. Whether this new development reflects *M. tanajoa's* adaptation to the cooler weather or the appearance of a new species has not been determined.

In general, the interactions between coccoids (mealybugs and scale insects) and their host plants are complex (Compere 1940; Miller and Kosztarab 1979), and one plant's susceptibility may vary from year to year. In some cases, when two plants of the same species are grown side by side, one may be only slightly attacked by a coccoid, whereas the other is heavily infested. Flanders (1970, in Miller and Kosztarab 1979) believed that these phenomena reflect an environmentally induced, physiologic resistance to a particular coccoid. He called this resistance phenoimmunity. According to him, edaphic factors or climatic changes can modify the physiology of the host plant and, in turn, modify the interactions between coccoid and host and cause — among other things — "differences in host immunity through time."

Discussion and Conclusions

The reduction of mealybug damage in Bas-Zaire and Bandundu is evident, but the mealybug problem in Zaire is not over. New areas are being infested and, even in those regions where the problem is reduced, colonies of mealybugs are still found; these colonies may serve as a source for future outbreaks. As experienced with many other pests, indigenous natural enemies alone, although valuable in reducing heavy mealybug infestations, are not expected to contain this pest.

As stated by Doutt and DeBach (1964), these natural enemies have not evolved with the pest but have "switched over from other similar pests," and do not generally regulate introduced pests. It is likely that the reduction of mealybug infestations is a cyclical phenomenon, bound to be reversed, caused by a combination of changes in the weather, physiology of the host plant, and, to a lesser extent, the action of local natural enemies. All research efforts must be continued to find a permanent solution to the cassava mealybug problem.

COMPARATIVE BIOECOLOGY OF TWO COCCINELLIDS, PREDATORS OF THE CASSAVA MEALYBUG, IN THE CONGO

G. FABRES[1] AND A. KIYINDOU[2]

Within the biocenosis of the cassava mealybug (*Phenacoccus manihoti*), two coccinellid species, i.e., *Exochomus flaviventris* and *Hyperaspis senegalensis hottentotta*, stand out because of their large numbers and their constant presence in the ecosystem. The biological parameters of these two predators were studied in the laboratory. The biological cycle, development time of different stages, sex ratio, as well as fertility and longevity of the females were determined. Using the data, we calculated the intrinsic rate of multiplication of each species and compared the control potential of these two local aids to pest control. In the field, population dynamics were studied along with those of the mealybug. The range of variation in population numbers in each species and the time of emergence in the field were recorded. This information allows one to define the role played by the species in regulating mealybug populations. It also should serve to direct the choice of exotic species to be introduced to supplement these insects' predatory activity.

The entomofauna associated with the cassava mealybug (*Phenacoccus manihoti*) abounds, particularly polyphagous predators during each dry season. Among these various biological control agents, the coccinellids, *Exochomus flaviventris* and *Hyperaspis senegalensis hottentotta*, drew our attention because of the consistency with which they were found in cassava fields, the sizable increase in their populations during gradation of the mealybug, and their potential impact on mealybug numbers. A comparative morphological study has already been published. The present paper deals with the bioecological parameters of these two species.

MATERIAL AND METHODS

Exochomus flaviventris and *H. s. hottentotta* strains were obtained from the Kombe district, 17 km from Brazzaville. The larvae were raised individually in plastic containers with screen lids for ventilation. The bottom of the containers was covered with filter paper, which was moistened regularly. The adults were reared in pairs in identical containers. Food consisted of excessive amounts of *P. manihoti* eggs in ovisacs.

The experiment was conducted simultaneously in both species at a mean temperature 26°C (range 21°–31°C) and relative humidity 70% (range 61–89%). These values correspond with conditions recorded at Kombe. The photoperiod was 12 h.

We studied duration of embryonic development, duration of development of different preimago stages, duration of female sexual maturity, sex ratio, female longevity and fertility. On the basis of these findings, we drew up life tables and calculated the intrinsic rate of multiplication for each species.

Fluctuations in the numbers of both species were recorded along with the development of gradation in *P. manihoti* during a field study conducted in 1979, which was a remarkably typical year. We followed the biological cycle of the predators in nature, compared the gradation profiles of their populations, and, adopting the same approach as in the laboratory, studied the potential of each of these organisms for controlling the phytophagous insect.

RESULTS

A study of the development cycle in the laboratory revealed that the incubation time was virtually the same in both coccinellids (Table 1). The most marked differences in development time were recorded during the larval stages (es-

[1] Office de la recherche scientifique et technique outre-mer, Brazzaville, People's Republic of Congo.
[2] Direction de la recherche scientifique, Brazzaville, People's Republic of Congo.

Table 1. Pre-imago coccinellid development (in days).

Stage	*H. senegalensis hottentotta* (27)		*E. flaviventris* (25)	
	Mean	Range	Mean	Range
Egg larva	6.5	5–9	6.2	6–7
L1	3.0	2–6	4.1	4–5
L2	1.9	1–4	4.6	4–6
L3	2.0	1–3	5.7	5–7
L4	8.8	7–11	11.9	10–15
Nymph	10.6	9–12	8.3	7–11
All	33.07	31–37	40.8	36–51

Table 2. Longevity and fertility of laboratory-reared *H. s. hottentotta* and *E. flaviventris*.

	H. s. hottentotta		*E. flaviventris*	
	Mean	Range	Mean	Range
Longevity of adults (days)	172.3	129–186	112.2	80–159
Preoviposition (days)	8	3–16	15	9–21
Overall fertility (eggs/female)	289.3	9–1081	125.4	7–337
Mean daily fertility (eggs/female/day)	2.3	0–9	1.9	0.1–5.8

pecially stages L_2 and L_3). On an overall basis, pre-imago development was shorter in *H. s. hottentotta* than in *E. flaviventris* (33.07 and 40.8 days, respectively).

Egg-laying began an average 8 days after emergence of the female in *H. s. hottentotta* and after 15 days in *E. flaviventris* (Table 2). In *H. s. hottentotta*, females represented 43.5% of the total population, whereas in *E. flaviventris*, the females were 58.9%. These figures are similar to those recorded in the field, i.e., 43.6% females for *H. s. hottentotta* and 55.2% for *E. flaviventris*. These findings will be used later to calculate the reproductive capacity of each species.

Exochomus flaviventris females had a shorter lifespan than *H. s. hottentotta* females (112.2 days vs 172.3 days) and laid fewer eggs (Table 2). Life and fertility tables for both species (Fig. 1 and 2) supplement the findings by showing that, in *H. s. hottentotta*, fertility decreases very rapidly with the age of the females (Fig. 1), a trend not noted in *E. flaviventris* (Fig. 2).

On the basis of findings during rearing operations involving the larval stages and pairs, we calculated multiplication rates, taking into account development time, sex ratio, longevity, and fertility and quantified the reproductive potential of a coccinellid population. When one knows whether a female is likely to be alive at age x (lx) and how many eggs she will likely lay between age x-1 and age x (mx), then the intrinsic rate of multiplication can be calculated from the formula, rc ($\log_e$ Ro/Tc) where Ro = lxmx, the net multiplication rate; Tc = age of the female when half of her eggs have been laid; and rc = reproductive capacity.

Langhlin's parameter may be considered here a good mathematical approach that is both more complex and less clearcut in its biological significance because it is used for comparative purposes. It can be extrapolated in the field where only two or three coccinellid generations develop during the dry season.

The reproductive capacity of each species was determined. Theoretically, under the conditions of the study, *E. flaviventris* increased its population by a factor of 66.6 in a generation lasting 77 days, whereas *H.S. hottentotta*, multiplied 123.7 times in 64 days. Thus, *H. s. hottentotta*, which was able to increase its numbers quicker and more effectively than *E. flaviventris* under iden-

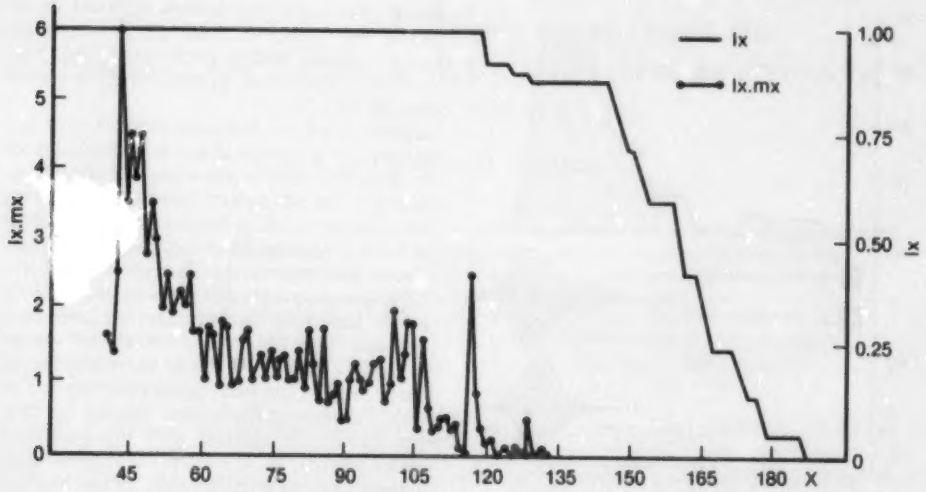


Fig. 1. *Fertility of female* H.s. hottentotta *as a function of age.*

tical conditions of development, should be found in greater numbers on *P. manihoti* colonies in cassava fields.

We conducted a field study to test this hypothesis. Chronological variations in prey numbers were studied along with fluctuations in the population densities of *E. flaviventris* and *H. s. hottentotta* in a cassava field. We counted all the developing stages of the mealybugs found on 30 stem apices picked at random, all the developing stages of both coccinellids on the colonies examined, and adults from both coccinellid species collected in limed traps. With the findings obtained, we traced the gradation profile of the bug and its two predators (Fig. 3).

The gradation profiles of the two coccinellids

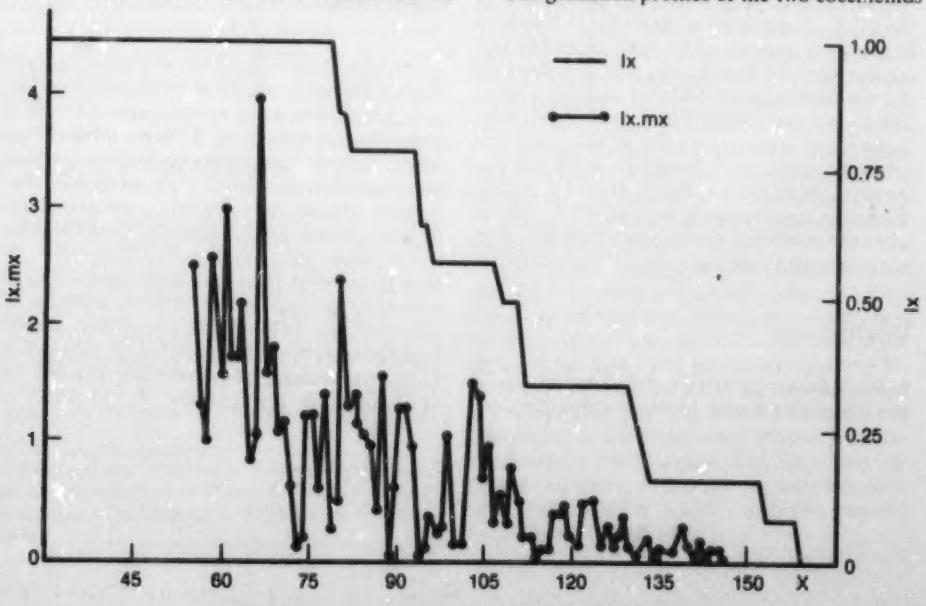


Fig. 2. *Fertility of female* E. flaviventris *as a function of age.*

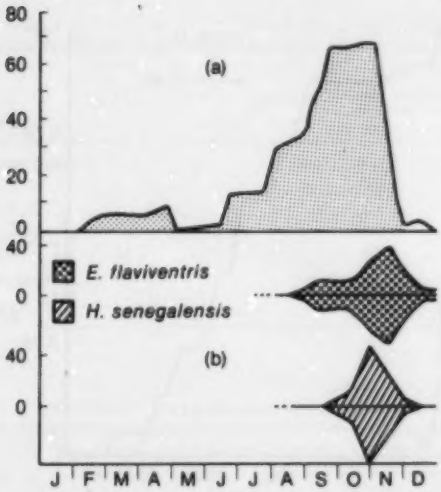


Fig. 3. *Gradation profile of (a) the cassava mealybug and (b) two of its predators.*

are a perfect illustration of laboratory breeding results: *H. s. hottentotta* increased far more rapidly and effectively than *E. flaviventris* (48 *H. s. hottentotta* individuals in the last week of October as opposed to 39 *E. flaviventris* specimens in the 3rd week of November). *Exochomus flaviventris*, however, was found more consistently in the fields. It appeared in August and remained in relatively large numbers until the end of December, whereas populations of *H. s. hottentotta* did not develop until October and November. The former can maintain its population on relatively small numbers of the phytophage and intervene early, even though its predation potential is not so great as that of *H. s. hottentotta*. The latter, unfortunately, only grows in number when the mealybug population is high and does not intervene in the early stages of gradation.

Discussion

When both coccinellid species were studied in the laboratory under identical conditions, we found that their populations differed in reproductive capacities, with *H. s. hottentotta* being a much better performer and, theoretically, equipped to control *P. manihoti* populations.

Conditions — both ecological and behavioural — in the field are far removed from the relatively simple experimental conditions created in the laboratory, and results may vary widely. In nature, *H. s. hottentotta* is abundant at the time of pullulation of the prey but emerges late and disappears early. There are several possible explanations for this phenomenon: abiotic factors, especially temperature, may not have the same effect on the two coccinellid species during the transition from the cool season (June–July) to the hot season (starting in August). *Exochomus flaviventris* females lay their eggs directly in contact with the mealybug ovisacs whereas *H. s. hottentotta* females often lay their eggs on branches that do not harbour any mealybugs. As a result, mortality among the larvae may be high while searching for prey. The presence of the pest may differ in its stimulatory effect on the species.

Autecology and ethology studies are needed if we are to determine the role these coccinellids could play as pest-control agents.

Conclusions

The plan to introduce New World predators to control the mealybug involves establishing exotic coccinellids in a new environment. Our study gives clearcut indications of characteristics that would complement local coccinellids without becoming their competitors. In our opinion, the exotic predators should be able to maintain their numbers on low-density populations of the prey, like *E. flaviventris*, but, like *H. s. hottentotta*, be able to increase their numbers rapidly and to intervene as soon as the mealybug begins to pullulate. We believe that researchers should begin systematically to screen exotic coccinellids to find organisms that are best able to meet the criteria we have just outlined.

EFFECTS OF FERTILIZER APPLICATION ON POSTEMBRYONIC DEVELOPMENT AND REPRODUCTION OF THE CASSAVA MEALYBUG

K.M. LEMA AND N.M. MAHUNGU[1]

Experiments were conducted with two cassava varieties in the greenhouse to ascertain the effect of NPK, N, and K fertilizer application on the postembryonic development and reproduction of the cassava mealybug, *Phenacoccus manihoti*. Nitrogen and NPK were applied at the rates of 60, 120, and 190 kg/ha and potassium (K_2O) at the rates of 15, 30, and 45 kg/ha. The results showed that none of the applications significantly ($P < 0.05$) affected either the development or the fertility of the mealybug on the two cassava varieties.

Fertilizer applications are known to affect mealybug populations and infestations. Fennah (1959, in Miller and Kosztarab 1979) reported that nitrogen application increased populations of *Planococcus citri* on cocoa in Trinidad. Potassium decreased, whereas phosphorus did not significantly affect, *P. citri*. Smirnoff and Valero (1975, cited by Miller and Kosztarab 1979) found that fertilization of jack pine with urea drastically increased infestations by the coccoid *Toumeyella parvicornis*, whereas fertilization with potassium reduced coccoid populations. The experiments reported here were carried out to ascertain the effects of NPK, N, and K fertilizers on the postembryonic development and fertility of *Phenacoccus manihoti*, as these two parameters influence insect populations and abundance.

MATERIALS AND METHODS

The two separate experiments were carried out in a greenhouse. Plastic pots (25 cm diameter) were filled with forest soil (total N 0.16%; P 47.4 μg/g; K 75.0 μg/g), and one cassava cutting was planted in each pot. Two cassava varieties, TMS 30001 and TMS 30572, were used. In the first experiment, N, P_2O_5, K_2O (15 : 15 : 15) fertilizer was applied 4 weeks after planting (WAP) at the rates of 60, 120, and 180 kg/ha. Three pots were used for each fertilizer level and for each cassava variety. Three other pots of each variety were not fertilized and were used as controls. The experiment was replicated twice. The pots were watered every day. A hygrothermograph placed in the middle of the greenhouse recorded the temperature and relative humidity. The average daily temperature ($\bar{X} \pm SD$) was 29.4 ± 2.01°C, and the relative humidity was 66.79 ± 6.38%.

One week after fertilizer application, the plants were artificially infested with freshly hatched, unfed mealybug nymphs (crawlers). We placed one crawler onto each leaf, using a camel-hair brush. About 24 h after the infestation, the crawlers were checked, and those that were established were numbered. A maximum of five crawlers was kept per plant. The crawlers were observed daily for cast skin indicating ecdysis, and the development of each nymphal stage was recorded. When the mealybugs started ovipositing, the eggs were removed every 3 days by means of an insect pin and counted under a binocular microscope.

In the second experiment, the effects of nitrogen and potassium were tested separately on the same cassava varieties. Nitrogen (calcium ammonium nitrate) was applied at the rates of 60, 120, and 180 kg/ha and potassium (K_2O) at 15, 30, and 45 kg/ha. Half the fertilizer was applied at 4 weeks after planting, and the remainder at 2 weeks after the plants were infested with the crawlers, i.e., at 7 weeks. The eggs were removed and counted. The average daily temperature was 30.75 ± 1.19°C, and the relative humidity 64.71 ± 4.54%.

[1] International Institute of Tropical Agriculture, Ibadan, Nigeria; present address for N.M. Mahungu: Programme national manioc (PRONAM), Kinshasa, Zaire.

Table 1. Influence of NPK fertilizer application on the postembryonic development of the cassava mealybug reared on TMS 30001.

NPK application (kg/ha)	Life cycle (days, $\bar{X} \pm SE$)			
	I	II	III	IV
0	6.3 ± 0.5	4.7 ± 0.3	6.3 ± 0.2	5.3 ± 0.2
60	5.6 ± 0.3	5.1 ± 0.2	6.1 ± 0.2	4.7 ± 0.2
120	5.6 ± 0.4	4.8 ± 0.1	6.2 ± 0.2	4.9 ± 0.2
180	5.4 ± 0.2	4.7 ± 0.3	6.5 ± 0.2	4.7 ± 0.2

Table 2. Effect of N and K application on the fertility of the cassava mealybug reared on TMS 30001 and TMS 30572.[a]

Treatment	Eggs/female ($\bar{X} \pm SE$)	
	TMS 30001	TMS 30572
Control	331.3 ± 23.5	334.3 ± 46.9
Nitrogen (kg/ha)		
60	390.3 ± 50.0	378.4 ± 32.4
120	362.1 ± 34.9	260.0 ± 31.4
180	362.4 ± 41.3	277.7 ± 32.3
Potassium (kg/ha)		
60	345.6 ± 25.6	317.5 ± 37.5
120	354.4 ± 34.0	306.5 ± 20.7
180	378.3 ± 17.1	304.7 ± 29.0

[a]No significant differences were found between the means.

Results and Discussion

The results on cassava variety TMS 30572 in the first experiment are not reported because most of the mealybugs and their eggsacks were consumed by an unidentified species of ground lizard. No statistical analysis was done on the results, but apparently NPK levels used in this experiment did not significantly affect the postembryonic development of *P. manihoti* (Table 1). To complete the postembryonic development, the mealybug required 21.6 ± 0.2, 21.4 ± 0.3, and 21.3 ± 0.2, respectively, on plants fertilized with 60, 120, and 180 kg/ha and 22.3 ± 0.3 days, on the unfertilized control. Although the average number of eggs per female seemed to be highest at 180 kg NPK/ha, no significant differences were found between treatments (Table 2). Application of NPK fertilizer did not influence *P. manihoti* reproduction. The fertility was 360.4 ± 36.5, 392.3 ± 38.8, 347.5 ± 28.6, and 491.0 ± 21.5 eggs per female, respectively, for 0, 60, 120, and 180 kg NPK/ha.

The differences observed between the treatments were not statistically significant. However, for both cassava varieties, the highest mealybug fertility was observed at 60 kg N/ha.

In general, nitrogen has been shown to increase (and potassium to decrease) populations and infestations of coccoids (Miller and Kosztarab 1979). Applications of NPK, N, and K fertilizers at the rates in these experiments would not influence cassava mealybug in the field. However, fertilizer applications, like any other good agronomic practice, will ensure that the plants grow vigorously and, hence, will offer some protection against mealybug attack. The large variations in numbers of eggs laid by individual females may have masked differences attributable to fertilizer applications.

FUNCTIONAL RESPONSE OF *AMBLYSEIUS FUSTIS* TO INCREASING DENSITY OF ITS PREY *MONONYCHELLUS TANAJOA*

T.O. EZULIKE AND J.K.U. EMEHUTE[1]

We studied the functional response of *Amblyseius fustis* to increasing density of its prey *Mononychellus tanajoa*. The experiment was conducted in the laboratory at a temperature of 24–29°C and relative humidity of 50–73%. In tests at eight densities of prey (10, 20, 30, 40, 50, 60, 70, and 80 nymphs and adults), the predator increased its consumption of prey up to a maximum at a density of 40. The number of eggs laid by the predator was not influenced by prey density. The functional-response curve is typical of invertebrate predators.

At the National Root Crops Research Institute (NRCRI), Umudike, Nigeria, we have been studying the effectiveness of phytoseiid mites as predators of *Mononychellus tanajoa*, which, since its introduction into the country in 1973, has become a major threat to cassava. According to Huffaker et al. (1971), the first step in assessing the performance of a predator is to learn how it acts as an individual, i.e., the way in which it searches for prey and discriminates between individuals for attack. These responses are the basis for models of predator–prey interactions, an understanding of which is essential for development of realistic strategies and tactics of control.

Amblyseius fustis, an indigenous phytoseiid mite in Nigeria, preys on green spider mite (Ezulike and Odebiyi 1982), as well as red spider mite. We evaluated its response to increasing densities of *M. tanajoa*.

MATERIALS AND METHODS

In the laboratory of the NRCRI, at a temperature fluctuating between 24° and 29°C and relative humidity between 50% and 73%, the response of *A. fustis* to prey densities of 10, 20, 30, 40, 50, 60, 70, and 80 (nymphs and adults) was studied. A pair of male and female *A. fustis* were used for each of the prey densities. Each feeding regimen was replicated five times. The dead spider mites were removed daily and replaced with live ones to maintain the density.

Any eggs produced by female prey were removed to ensure that the predators were feeding only on the adult prey. Daily records of prey consumption and fecundity were kept. The number of prey consumed by the mated male or female was computed as the average consumption of the two individuals because the females were removed from the rearing units during oviposition.

RESULTS AND DISCUSSION

Consumption of prey by mated males and females increased gradually up to a maximum at a prey density of 40 (Fig. 1) and diminished at densities higher than 40.

Generally, more nymphs were consumed than adults probably because of size differences. The adult *A. fustis* attacked and consumed adult spider mites, which are actually slightly larger than the predators, but the nymphs were easier to handle. Our procedure did not control for the possibility that *A. fustis* fed on eggs laid during the night, but, according to findings by McMurtry and Scriven (1964), egg feeding probably had an insignificant effect on the number of prey consumed.

The functional-response curve of *A. fustis* was typical of invertebrate predators. Consumption increased with prey density up to predator satiation when further increases in prey density tended to decrease consumption. In a similar experiment, Mori (1969) observed that the number of *Tetranychus urticae* consumed by *Amblyseius longispinosus* diminished significantly

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

at high prey densities. Holling (1965) identified four components of functional response: the rate of successful search, the time available for searching, the time spent in handling prey, and the hunger level of the predator. Our findings are in line with those of others (McMurtry and Scriven 1966; Mansour et al. 1980).

The number of eggs laid at the eight densities of prey varied (Fig. 2) and was independent of the prey density and prey consumed.

The response under laboratory conditions does not necessarily indicate inability of a predator to control and regulate its prey under field conditions. Although the predator reduced its consumption of prey at densities higher than 40 : 1, such high concentrations are unlikely to occur outside a controlled environment.

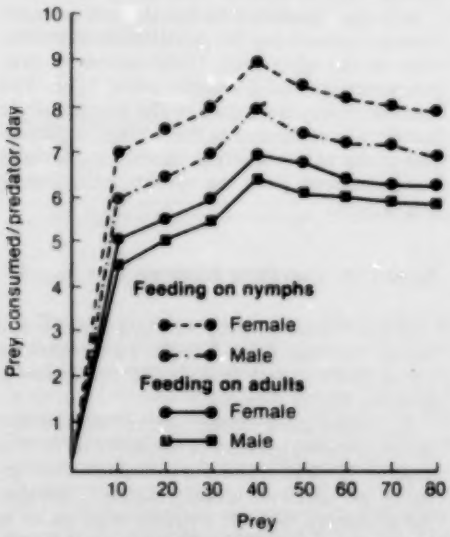


Fig. 1. *Average number of* M. tanajoa *consumed by mated* A. fustis.

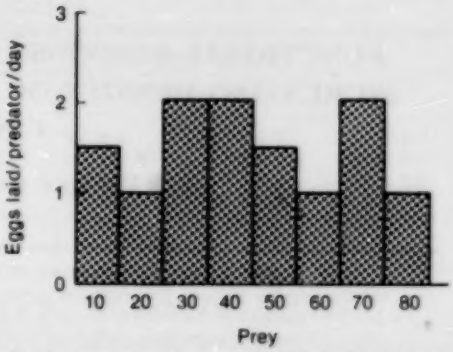


Fig. 2. *Average number of eggs laid by female* A. fustis.

Several authors have shown that when the ratio of prey to predator is low initially, phytoseiid mites are effective agents for biological control. Collyer (1958) reported that when 5, 25, or 50 *Panonychus ulmi* were placed on a plant with 5 *Typhlodromus pyri*, the prey population remained at a low density for the next 3 months. Bravenboer and Dosse (1962) reported that *Phytoseiulus persimilis* was able to control *Tetranychus cinnabarinus* best when liberated at rather low populations of prey.

Conclusion

Amblyseius fustis is a fast-running predatory mite with a good ability to locate prey. These are essential characteristics of an effective natural enemy (Huffaker et al. 1971). The predator spent only a short time in killing its prey and appears to have great potential for high rates of consumption.

We are grateful to the Director of the National Root Crops Research Institute, Umudike, Dr L.S.O. Ene, for the facilities for this study and permission to publish it.

Control of the cassava green mite in Uganda

B. Odongo and G.W. Otim-Nape[1]

Investigations were conducted at Serere Agricultural Research Station (eastern Uganda) to identify and promote resistance of cassava to *Mononychellus tanajoa*, the most destructive arthropod pest of cassava in the country. Six cassava families that were imported from the International Institute of Tropical Agriculture, Nigeria, as seeds and included in the breeding program exhibited different degrees of hairiness of leaf surface. When they were subjected to severe mite attack during the dry season, their resistance correlated with the number of hairs on the leaves. This information helped in selecting cassava varieties with high mite resistance.

The cassava green mite (CGM) was introduced into Africa through Uganda where it was reported near Kampala in 1972 (Nyiira 1975). It has now spread to Tanzania, Kenya, Sudan, Zaire, Rwanda, Burundi, Nigeria, Benin, and Togo (Leuschner 1982). The mite has been recorded feeding and breeding on *Manihot esculenta*, *M. glaziovii*, *M. dichotoma*, *M. piauhensis*, *M. heterophylla*, and *M. cartholgenensis* (Nyiira 1978).

The ecological distribution and biology of CGM have been intensively studied, with the most severe outbreaks being linked to drought and poor soil conditions (Nyiira 1982). The pest attacks the shoots and causes a reduction in young leaf development and eventually affecting root size, root quality, and time for root formation (Nyiira 1982).

Because of the socioeconomic conditions in Africa, use of acaricides has not been recommended as a control measure; emphasis has been on biological and integrated control.

At the Serere Agricultural Research Station in Uganda, we have been screening seedlings of six families in an attempt to confirm resistance to CGM and to determine the relationship between mite resistance and the hairiness of cassava leaves.

Methods

Open-pollinated seeds of six cassava families imported from the International Institute of Tropical Agriculture, Nigeria — IYT (1979) bulk; 30395 (1979) bulk; 30572 (1980) bulk; 30555 (1979) bulk; PYT (1980) bulk; AYT (1979) bulk — were planted in a seedling nursery, at a spacing of 50 cm × 50 cm. The seedlings were infested naturally by CGM, and, at 6 months, when mite infestation was greatest, the symptoms were scored on a scale of 0–5, where 0 was no mite damage and 5, serious damage including defoliation at the top of the shoot. Each plant was scored for resistance or susceptibility. Using hand-held lenses, staff at the station also scored hairiness of leaves and shoot tops on a scale of 0–5, where 0 was no hair and 5, profuse and dense forked trichomes.

Results and Discussion

Of the cassava families tested, 30395 and 30572 performed best. From family 30395, 2.63% of the seedlings had a score of 0 for mite damage and 3.29%, a score of 2. In leaf and shoot hairiness, 0.66% and 1.97% of the seedlings scored 4 and 5, respectively. For 30572, the percentages of seedlings scoring 0 and 2 for mite damage were 1.80 and 6.31. Seedlings from family 30555 were the most liable to mite damage and were the least hairy (Table 1). A majority of the seedlings scored 3–5 for mite damage and 0–1 for hairiness. Those scoring 4 or 5 were considered susceptible; 3, tolerant; 0–2, resistant.

The investigation revealed that some "resistant" individuals harboured a number of mites

[1] National Root Crops Improvement Programme, Serere Agricultural Research Station, Soroti, Uganda.

Table 1. Mite score and pubescence of seedlings of six selected families, Uganda.

	Seedlings tested	% seedlings in mite damage score						% hairiness score					
		0	1	2	3	4	5	0	1	2	3	4	5
IYT (OP) 1979	241	0	0.83	1.24	21.49	30.58	46.69	87.60	9.92	2.07	0.41	0	0
30395 (OP) 1979	132	2.63	0	3.29	28.95	25.00	40.13	81.58	15.79	0	0	0.66	1.97
30572 (OP) 1980	95	1.80	0	6.31	39.64	31.52	20.72	96.40	0	0	3.60	0	0
30555 (OP) 1979	183	0	0	0	14.83	22.88	62.29	99.58	0.42	0	0	0	0
PYT (OP) 1980	181	0	0.46	1.83	22.83	36.53	38.36	89.04	10.96	0	0	0	0
AYT (OP) 1979	180	0	0	1.90	21.52	32.91	43.67	86.61	11.39	0	0	0	0

without showing symptom development, that is, showed less sensitivity to mite attack.

The resistance of 30395 and 30572 has been reported elsewhere (IITA 1980), and its confirmation in Uganda implies that this characteristic is genetically stable and is likely to remain so across different environments and for a long time (CIAT 1979).

Dense trichomes have been observed to affect mite behaviour by making it difficult for the pests to rest along the leaf midrib. When the trichomes are closer than 0.2 mm, the mite finds it difficult to feed and rest because the average length and width of the female mite are 0.3 mm and 0.2 mm (IITA 1980). Cassava also has other defence mechanisms: HCN concentrations and unknown factors affecting development, length of adult lives, and nymph mortality (CIAT 1979) — factors that may explain why family PYT 1980 is quite resistant despite its having few trichomes.

STUDIES ON THE NUTRIENT CONTENT OF YELLOW-PIGMENTED CASSAVA

O. SAFO-KANTANKA, P. ABOAGYE, S.A. AMARTEY, AND J.H. OLDHAM[1]

A local cultivar of yellow cassava, Bankye Borode (BB), was found to have begun to acquire pigmentation after 3 months of growth. We extracted the pigment, using petroleum ether in acetone (1 : 1) or hexane as solvent. The extract was purified by column chromatography. The absorption spectrum of the pigment corresponded with that of β-carotene, with peak absorption at 450 nm. The extract and β-carotene gave identical Rf values of 0.82 and 0.805, respectively, when chromatographed on silica-gel adsorbent. It was concluded that the yellow pigment is β-carotene, the precursor of vitamin A. A proximate analysis revealed that, apart from its carotenoid content, BB was not much different from Ankra, a local unpigmented cultivar, in nutrient composition.

Cassava is primarily a calorie-producing crop; however, there are certain genotypes that have other important nutrients. One such genotype is the cultivated cassava with yellow-pigmented root flesh, referred to by Oduro (1981) as Bankye Borode (BB). Oduro (1981) mentioned that this genotype is well known and is preferred in preparations like fufu and gari in all the cassava-growing areas of Ghana. FAO (1970) data showed that white, pale yellow, and deep yellow varieties of sweet potato had 80, 500, and 7000 international units (IU) of vitamin A, respectively, and cassava had traces. The type of cassava used in the analysis was not given. Oduro (1981), therefore, concluded that yellow-pigmented cassava had a high vitamin A content. His conclusion prompted this work to find out the nutritive value, especially the vitamin A content, of the yellow-pigmented cassava.

MATERIALS AND METHODS

Stakes of a local yellow-pigmented cassava clone were obtained from Kotei, a suburb of Kumasi, and planted at the Arable Crops Research Farm of the Crop Science Department, University of Science and Technology, Kumasi, in June 1982, together with stakes of a local unpigmented cassava, Ankra.

A few stakes were harvested monthly, beginning at 3 months after planting so that the rate of pigmentation could be recorded. Chemical analyses on the nutrient composition of the tuber began 7 months after planting. A sample of the peeled tuber was ground, and the yellow pigment extracted by Booth's (1957) method. Petroleum ether in acetone (1 : 1) or hexane was used as solvent. Acetone was washed out of the extract, and the sample was chromatographed on an activated mixture of alumina and Na_2SO_4 to purify it.

To identify the pigment, we determined the absorption spectrum of the extract, using a Baush and Lomb spectrometer 20 and compared the spectrum with pigments of known absorption spectra. The extract and pure β-carotene were chromatographed on silica-gel adsorbent (activated at 110°C for 1 h), and the Rf values determined. We read the absorbency of a portion of purified extract in a spectrometer against a blank of petroleum ether (60–80°C) and compared it with the corresponding concentration from a standard curve of β-carotene. The amount of carotene was determined at 7, 8, and 9 months after planting. A sample was sun-dried as is normally done for a food preparation called kokonte, and the carotenoid content of the resulting flour determined. The carotenoid content of gari prepared from BB was also determined.

RESULTS AND DISCUSSION

The diameter of roots harvested at 3 months ranged from 0.6 to 1.2 cm. Tuberization had not

[1] Crop Science Department and Biochemistry Department, University of Science and Technology, Kumasi, Ghana.

Table 1. Nutrient composition of yellow- and white-pigmented cassava.

	Harvesting date (months after planting)			
	7		10	
	Yellow	White	Yellow	White
Moisture	59.4	56.3	69.3	63.3
Crude protein	0.83	0.54	1.03	0.74
Crude fibre	0.88	1.11	1.05	1.16
Total carbohydrates	37.85	41.04	—	—
Crude fat	0.56	0.28	2.01	0.35
Ash	0.50	0.67	0.14	0.39

yet begun in Ankra. At this stage, the yellow pigment could only be observed in the pith and the area immediately around it. At 4 months, the yellow pigment could be seen in the pith and the rays spreading from it. The spread of the pigment from the pith continued until, at 6 months, it could be seen in all parts of the root. The progressive increase in the amount of pigment was also observed by Oduro (1981) and was borne out by the quantitative analysis that began at 7 months after planting. The pigment, like all other parts of the root, seems to be synthesized in the leaves and transported to the storage organ.

The absorption spectrum of the extract was between 450 and 455 nm when petroleum ether in acetone was the extracting solvent and between 445 and 450 nm in hexane. These figures coincided with the absorption peak (450 nm) of pure β-carotene. We, therefore, concluded that the extracted pigment was β-carotene. This conclusion was confirmed by thin-layer chromatography, in which the extract and β-carotene had Rf values of 0.82 and 0.805 respectively. As β-carotene is the precursor of vitamin A, this result agrees with the FAO data that showed yellow-pigmented sweet potato had a high content of vitamin A.

The carotenoid content of the fresh cassava increased with age, being 300, 325, and 350.6 g/100 g. The gari that was prepared with grated, fermented, and roasted cassava had the popular yellow appearance, which is sometimes imitated by addition of palm oil when unpigmented cassava is being roasted for gari. The reduction in carotenoid content in these food preparations compared with the fresh sample probably reflects the oxidation of the β-carotene in the sun or during roasting.

The nutritive values of BB and Ankra were similar (Table 1), and the cyanide content of the BB fresh root was 0.899 compared with 1.07 mg/10 g in Ankra.

These results show that the superiority of BB over Ankra lies mainly in the yellow pigment or carotenoids of BB, which provide β-carotene, the precursor of vitamin A.

MICROBIAL BREAKDOWN OF LINAMARIN IN FERMENTING CASSAVA PULP

M.A.N. EJIOFOR[1] AND NDUKA OKAFOR[2]

Linamarin-hydrolyzing microorganisms were inoculated into fresh cassava pulp. The bacteria and yeasts grew well: generation times were 59, 58, 78, and 74 minutes for *Alcaligenes faecalis*, *Leuconostoc mesenteroides*, *Saccharomyces cerevisiae*, and *Rhodotorula minuta*, respectively. They hydrolyzed cassava linamarin, releasing 0.090, 0.094, 0.102, and 0.100 mg HCN/g of pulp, respectively. Alone, the linamarase endogenous to the cassava released only 0.045 mg HCN/g of pulp. We believe, therefore, that the four microorganisms can be used in the commercial detoxification of cassava pulp during the production of gari or other fermented cassava-based meals.

Earlier, we (1981) suggested that microbial means be used to reduce the cyanide level of cassava. We had found that the cyanide level was drastically reduced during the natural fermentation of cassava and felt that the reduction was caused partially by microbial enzymatic activity. As far as we know, no other researchers have investigated the potential for microbial hydrolysis, but we have identified several microorganisms capable of breaking down linamarin in purified form: *Alcaligenes faecalis*, *Leuconostoc mesenteroides*, *Saccharomyces cerevisiae*, *Rhodotorula minuta*, *Fusarium oxysporium*, *Aspergillus niger*, and *A. flavus*. Of these, *F. oxysporium*, *A. niger*, and *A. flavus* have been reported to be sources of food poisoning and diseases (Frazier 1971; Banwart 1979). Also, fungal forms that cause spoilage in foods, i.e., those with hyphal strands and spores that readily destroy the colour and texture of the products, should be eliminated from further work. We tested the abilities of four of the organisms, individually and collectively, to grow in and detoxify cassava pulp. A safe and cheap method of preserving the organisms for supply to the farmer has not yet been worked out.

MATERIALS AND METHODS

A fresh root harvested from 1-year-old cassava (Nwugo variety) was washed, peeled, and rewashed. The peeled root was immersed completely in 70% ethanol for 1 minute and flamed. The sterile outer tissue was charred. We removed a cylinder of tissue (1.2 cm in diameter) aseptically, using a sterile cork borer. We cut 1 cm of the tissue from both ends, aseptically transferring and crushing the remaining 10.5 cm. The pulp was tested and was found to be sterile.

We then placed 10-g portions of pulp into 250-mL volumetric flasks. A sterile 10-mL bottle without stopper was gently placed upright in the centre of the bottom of each flask, and 2 mL of 0.1 M NaOH was pipetted into the bottle. One flask was set aside as a control. The pulp in the other flasks was inoculated with five loopfuls of organism. All the flasks were firmly stoppered with sterile cotton wool and incubated in a Gallenkamp orbital incubator (rotating at 100 rpm for 144 h at 28°C). The hydrocyanic acid released was trapped in the NaOH solution, whereas the glucose liberated was left in the pulp medium. All gases released were tested for ammonia. The pulp was sampled for HCN at 24-h intervals by the methods of Aldridge (1944) and Epstein (1947) as modified by Jorgensen. Different combinations of the organisms were also used, and the rate at which they broke down linamarin was assayed. The results were statistically analyzed, and changes in the populations and generation times were determined. The pH of growth in the pulp was monitored.

The effect of HCN on the survival and growth of the microorganisms was also studied. A 0.1% solution of sodium cyanide was incorporated in glucose yeast agar (GYA) and broth and was dispensed in 50-mL amounts into 250-mL flasks. The pH was adjusted to 6.5 and 5.0 for the

[1] Cassava Programme, National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

[2] Anambra State University of Technology, Awka, Nigeria.

Table 1. Mean HCN (mg) released from 1 g of pulp by the microorganisms.

Time (h)	Pulp only	*A. faecalis*	*L. mesenteroides*	*S. cerevisiae*	*R. minuta*
0	0.008	0.008	0.006	0.009	0.008
24	0.020	0.062	0.036	0.026	0.032
48	0.032	0.082	0.088	0.042	0.070
72	0.045	0.090	0.100	0.102	0.094
96	0.051	0.078	0.094	0.105	0.108
120	0.058	0.060	0.082	0.086	0.092
144	0.065	0.038	0.046	0.052	0.045

bacteria and yeasts, respectively. Eight separate flasks were prepared, two for each organism. Thereafter, five loopfuls of each organism were used to inoculate the broth in each flask. Immediately, microbial cell counts were estimated from 0.025 mL of the broth placed on dried GYA plates, evenly spread on the surface of the agar, and allowed to dry before being incubated at 28°C overnight.

Sodium cyanide crystals (1 g) were dissolved in distilled water, the final volume being 1 L. The solution was dispensed in two equal portions, one for the GYA plates and the other for the broth. Both were seeded with the organisms and contained 0.1% cyanide. Other plates and tubes contained 0.2%, 0.3%, and 0.4%. The mouths of the tubes containing the broth were stoppered with filter paper previously wetted with Nessler reagent. After incubation (72 h) at 28°C, the tubes were warmed to 50°C in a water bath and observed for colour change (Collins and Lyne 1976). The agar plates were observed for appearance of colonies.

In studies of the preservation of the microorganisms for supply, we peeled 1 kg of fresh cassava roots. The cortex was washed, hand grated, and oven-dried to about 50% moisture. We then treated one-half of the substance with $(NH_4)_2SO_4$, 0.1%; KH_2PO_4, 0.05%; K_2HPO_4, 0.05%; $MgSO_4$, 0.02%, $CaCl_2$, 0.02%, and NaCl 0.03% to bring the water activity of the pulp to about 0.70. This substance was to be used for the bacteria. The other half was treated with K_2HPO_4, 0.87%; $(NH_4)_2SO_4$, 0.4%; $MgSO_4 \cdot 7H_2O$, 0.05%; $CaCl_2$, 0.03%, were incorporated, the water activity being about 0.67. This substance was to be tested as a medium for maintaining the yeast. Treating the pulp with these salt concentrations ensured the water activity was maintained at the desired level and prevented further microbial growth. The pH of the pulp mixtures was maintained at 5.0 for the bacteria and 3.0 for the yeasts. The mixtures were divided into 10-g portions and placed in dry, sterile universal bottles along with 10 loopfuls of pure culture of one organism. Each bottle was made airtight and stored at 4°C. Later, fresh pulp was inoculated with the culture and allowed to ferment at room temperature for 24 h before being pressed for assessments of the juice.

Results

The HCN and glucose released when the organisms were seeded on fresh pulp increased with time (Table 1) up to a maximum at 72 h for the bacteria — *A. faecalis* and *L. mesenteroides* — and at 96 h for the yeasts — *S. cerevisiae* and *R. minuta*. The control maintained a steady, although gradual, increase in the amount of HCN released up to 144 h (Table 1).

A highly significant ($P < 0.01$) difference existed between the levels of HCN released by cassava linamarase when acting alone and those released when it was acting in combination with the microorganisms.

The ability of the organisms to grow on the linamarin was shown by the growth patterns obtained when viable cell counts were taken. In the cassava pulp, the population of each organism was appreciably affected by the increase in time of fermentation. The bacteria started off with a rapid increase in number until they had tripled at about 72 h. Thereafter, there was a steady fall in the number of viable cells. The yeasts, on the other hand, took longer (48 h) to show appreciable increases in population. Subsequently, rapid increases in growth were observed and were maintained until after 96 h when the number of viable cells was more than five times the initial amount and *S. cerevisiae* had reached a plateau. *Rhodotorula minuta* continued to increase. The generation times for *A. faecalis*, *L. mesenteroides*, *S. cerevisiae*, and *R. minuta* were derived as 59, 58, 78, and 74 minutes, respectively. The pH of the pulp medium was also affected by the fermentation. The acidity was observed to increase gradually, although this increase be-

came less pronounced after 96 h. The yeasts produced a greater drop in pH than did the bacteria.

In-vitro studies showed that *S. cerevisiae* could grow without detectable inhibition when 1% solution of sodium cyanide was incorporated in its growth medium. Ammonia was liberated.

When combinations of the organisms were used to inoculate fresh sterile pulp, we observed very rapid breakdown of linamarin when all the organisms were seeded together. Changes in pH were most pronounced when all four organisms were used.

The organisms preserved in the pulp medium were viable after 6 months. Dehydrating the pulp by oven-drying and by addition of salts reduced its water activity to the level required to control growth of the organisms and kept them viable at minimal cost.

Discussion

The four organisms are able to break down linamarin and to grow and multiply in fresh cassava pulp. This means they can grow effectively in the presence of low levels of cyanide. They probably survive either by inducing enzymes that degrade and detoxify liberated HCN or by forming cyanide-resistant enzymes. Knowles (1976) reported many microorganisms that degrade cyanide to nontoxic products, and bacteria have been reported to convert cyanide to CO_2 and ammonia, nitrite, or nitrate (Knowles 1976). The cyanide can also be detoxified by conversion of β-cyanoalanine or other products that are intermediate products in cyanide assimilation (Nartey 1981). This conversion has been widely reported and probably explains why, in our studies after 72 and 96 h, the levels of HCN declined in the pulp inoculated with microorganisms: some of the organisms metabolized and incorporated the cyanide. Detoxification by the bacteria and yeasts was most effective during the first 72 h and 96 h respectively. Most of the glucosides in the pulp are broken down and the HCN in bound and free forms is liberated, leaving only small quantities.

The cyanide content of fresh cassava roots, as reported by various workers, varies from 0.6 mg to 160 mg/100 g (Osuntokun 1970; Montaldo 1977). However, by the method of microbial hydrolysis, values as low as 3.8, 4.6, 5.2, and 4.5 mg/100 g were obtained — values considered to be innocuous.

Any subsequent processing (drying, washing, cooking, soaking, or pulverizing) should further reduce residual cyanide.

We wish to thank the departments of microbiology and biochemistry, University of Nigeria, Nsukka, and the National Root Crops Research Institute, Umudike, for most of the material and equipment used in this work.

PERFORMANCE OF A CASSAVA PEELING MACHINE

P.M. NWOKEDI[1]

Peeling constitutes a major problem in cassava processing in Nigeria. At present, the method of peeling is usually manual. This paper discusses the development, design, and manufacture of a peeling machine suitable for village use. The machine is an oval chamber that has holes cut along the walls and is lined with sharp wire gauze. Cassava roots are loaded in the chamber, which is mounted on two mild-steel rods, 35 cm in diameter, attached at either end. The rods allow the chamber to rotate clockwise. The left rod is connected to a 5-hp electric motor by means of a v-belt pulley. Thirty balls coated with wire gauze are added to the chamber. The machine is mounted on an angle — 33°. The angle permits the sharp edges of the chamber and balls to carry out effective abrasive peeling. The roots are cleaned as they are being peeled, the chamber passing through a water-filled pan underneath it.

Peeling is the most labour-intensive operation in processing cassava for use in traditional dishes in Nigeria. At present, peeling is done by hand. A peeling machine suitable for use at the village level would alleviate the drudgery involved in cassava processing and open the way for processing on a larger scale than household production. This thinking prompted my colleagues and me at the National Root Crops Research Institute (NRCRI) to design, manufacture, and test such a machine.

In designing the machine, we had to allow for the many variations in size and shape of roots from current varieties of cassava. The weight varies between 30 g and 400 g and there are spindle-shaped and carrot-like roots. The peels also vary in thickness, texture, and strength of adhesion to the root's flesh. The properties vary with the age of the roots both before and after harvest. Our task, therefore, was to design a peeling machine that would handle any roots from any source all year round.

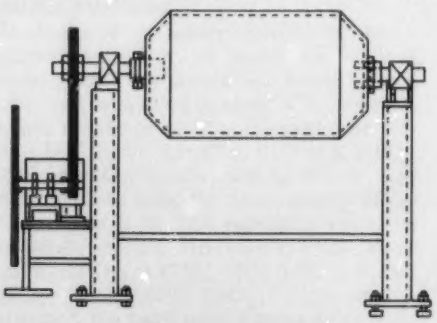


Fig. 1. *Front view of cassava peeler.*

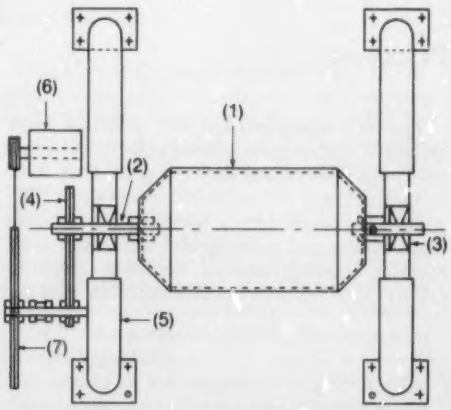
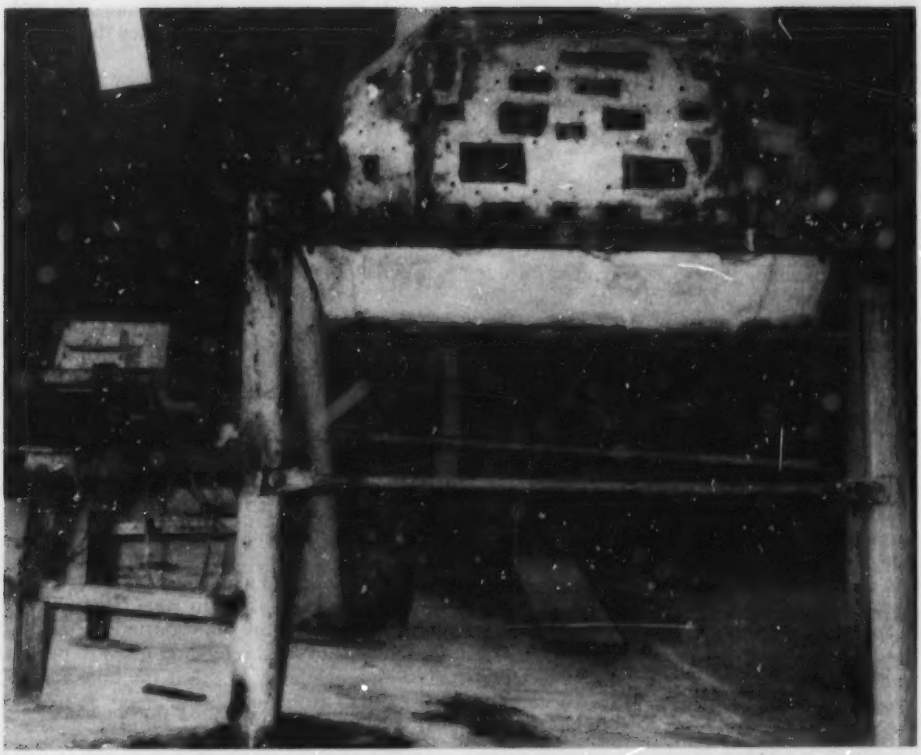


Fig. 2. *Plan for cassava peeler: (1) chamber, (2) support shaft, (3) roller bearing, (4) sprocket/chain, (5) frame, (6) electric motor, (7) pulley.*

Within these constraints, we devised a simple machine, an egg-shaped cylinder with an inner chamber or lining of sharp wire gauze. The cylinder has holes cut in the walls so that when it

[1] National Root Crops Research Institute, Engineering Research Department, Umudike, Umuahia, Nigeria.



The peeling machine is functional, simple to assemble, and inexpensive.

rotates through a water-filled pan mounted below it, the water passes through the holes to wash the roots. The cylinder is supported on 35-cm-diameter mild-steel pipes, attached at both ends. These pipes serve as short shafts that allow the cylinder to rotate clockwise. The left shaft is connected to a 5-hp diesel engine by means of a v-belt pulley. The chamber contains 30 balls that are also coated with wire gauze. The machine is mounted at an angle of 33°; in this position, the sharp-edged chamber and the balls carry out effective abrasive peeling of the cassava roots. The chamber rotates through the pan containing water. It can peel 300 kg of roots at one time. There are two protective galvanized plates that are attached to the sides of the water-pan to prevent water from spreading.

Performance Tests

We tested the performance of the cassava peeling machine with roots harvested from Western Farm (NRCRI). We divided 3000 kg roots into three batches — one batch was peeled that day, a second batch was peeled the next day, and the third batch was peeled by hand (the traditional method). All the roots were weighed before being peeled. Three persons performed the manual operation. Both the machine and manual operations were timed, and the peeled roots were weighed. Another series of tests were undertaken with 1000 kg roots, but this time the roots were cut into straight pieces and sorted by size — small, medium, and large — before being peeled by the machine.

Results and Discussion

Naturally, the ideal is that the machine will remove the peel completely without removing useful flesh (Odigboh 1978). Unlike yams or other tuber crops, the cassava has roots with a relatively loose peel or cortex. Hand-peeled roots average about 80% of the total weight of

unpeeled roots, that is, the peelings constitute about 20% of the total weight.

When the unsized sample was mechanically peeled, the weight of the sample was considerably lower than the hand-peeled control. The small roots were peeled before the large ones and had disappeared completely by the time the larger roots were peeled.

To quantify the performance based on the ratio of peeled and unpeeled roots, we used the equation E = W − Wa/W − We where E was peeling efficiency index; W was mass of unpeeled roots; Wa was actual mass of peeled roots; and We was mass of peeled roots that would be obtained if only the cortex were removed (0.95 − 1.8 W). The closer the value is to 1.00, the higher the peeling efficiency. E, when less than 1.00, corresponds to incomplete peeling. E greater than 1.8 indicates loss of useful root flesh.

The peeling machine was least efficient when handling unsized roots — 45%; hand trimming was necessary. In samples that were separated by size, some hand trimming was also necessary for the small roots, but the efficiency improved to 68%.

Performance was observed to be best for the medium and large roots, peeling being complete and the losses of flesh negligible. If not excessive, flesh loss is better than hand trimming, which is time-consuming. In addition, the machine efficiency was improved when the balls in the machine were various sizes.

The three people peeling roots by hand were able to peel 300 kg/day. Their peeling rate was lower on the 2nd and 3rd days than on the 1st day, probably because the roots dried out enough to make peeling by hand more difficult. The throughput in mass/unit time depends on the root sizes, with higher rates for larger roots. The machine's rate for unsized roots was 15 kg/h, whereas, for sized samples, was as high as 500–1000 kg/25 minutes. However, this rate does not include the time spent in cutting the cassava roots into straight chunks about 80–100 mm or sorting the cut pieces.

Conclusion

The cassava peeling machine has been perfected by the NRCRI for the past 3 years. The completion of the machine is planned this year. The peeler functions best with sized lots of cassava; when set up for a specific size range, it has a peeling efficiency of up to 80%. Because the cutting and sorting are time-consuming, the machine needs to be carefully adjusted to peel at maximum efficiency to offset the time and labour and to avoid hand trimming.

AN IMPROVED TECHNIQUE OF PROCESSING CASSAVA FUFU

FESTUS A. NUMFOR[1]

In tropical Africa, the preparation of fufu involves soaking (fermenting) peeled cassava roots for 3–5 days, mashing, sun-drying the pulp for 2–4 days, and milling into flour (2% protein). An attempt was made to improve on this time-consuming process and on the nutritional value of the product. Peeled roots were grated before being soaked, the result being that fermentation proceeded much faster than with the whole roots. When the grated pulp was inoculated with 3-day-old cassava liquor, the fermentation time was further reduced, and a simply designed solar/fire dryer reduced drying time substantially. The nutritional value was improved to 6% protein by the addition of full-fat soybean flour (10% of total weight). The product was not significantly different ($P < 0.05$) organoleptically from the unenriched flour.

Fufu — fermented cassava flour — is consumed in West and Central Africa, as far south as Angola and as far east as Madagascar. The roots are peeled, washed, steeped in water for 3–5 days until soft, pressed into pulp, sun-dried for 2–4 days, and then milled into flour. The steps, as in other traditional methods for cassava preparation, are aimed at reducing to innocuous levels the concentrations of toxic linamarin present naturally in the cassava roots. Unfortunately, fufu, as processed traditionally, is time-consuming (3–5 days' fermentation and 2–4 days' sun drying). There is usually exposure of the pulp to contamination during soaking and drying. Variability in yields, products that are not standardized, and lack of appropriate packaging have discouraged industrial processing.

This report describes studies to modify the process to give a more hygienic, nutritious, and standard product through reduction of fermentation and drying times; improvement of drying conditions; protein enrichment; and packaging.

MATERIALS AND METHODS

Cassava roots were peeled, washed, and divided into portions, 8 kg each. Those in the first group were left whole; those in the second and third groups were cut into 5- and 2-cm discs, respectively; and those in the fourth group were grated by hand. Each group was divided in half and steeped in 5 L tapwater or 3-day-old cassava liquor and allowed to ferment naturally. The liquor, 25 mL, was sampled immediately and every 24 h until the roots became soft. The acidity of the sampled liquor was determined by titration with 0.1N sodium hydroxide. The acidity was plotted against time for each group.

A simple, double-effect (solar/fire) dryer was designed, constructed, and compared with a laboratory oven, a Roucadil ventilated chamber, and sun drying.

Soybean was chosen for supplementation because of its high protein content, availability, and novelty.

A simple technique was designed to produce full-fat soybean flour with minimal enzymatic activity. The steps involved washing the beans, soaking them 5 h, removing the hulls, steaming 20 minutes, drying, and milling.

Samples of fufu were enriched with the flour at 0, 5, 10, 15, and 20% of total weight. Fufu paste was prepared (traditional method) from these composite flours and their organoleptic properties compared by a taste panel (accustomed to fufu eating) of nine. At 10% level of substitution, there was no significant organoleptic difference ($P < 0.05$) between the composite and the unenriched flour. These promising results prompted a larger taste test: 55 households were chosen in the Western Province of Cameroon, and each participant was given 1 kg of the enriched fufu sample, packaged in a transparent polyethylene bag; asked to prepare it the usual

[1] Institute of Agronomic Research, Njombe, Cameroon.

Table 1. Some major characteristics of four systems for drying cassava pulp.

System	Capacity (kg of pulp)	Drying temperature (°C)	Time (h)	Cost 1000 (CFA)
Lequeux laboratory oven	10	58	24	800
Roucadil ventilated chamber	1000	55	10	5000
Double-effect dryer	200	48	28	150
Open sun drying	Infinite	25	96	—

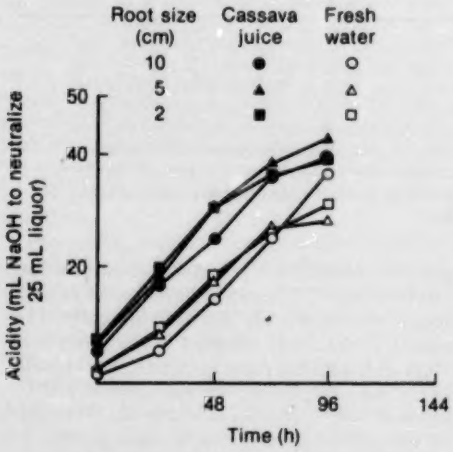


Fig. 1. *Effect of root size and medium (cassava juice or fresh water) on cassava fermentation.*

way; taste it; and complete a questionnaire accompanying the sample.

Proximate analysis was carried out to compare the enriched and unenriched fufu. The samples were oven-dried at 105°C for 5 h for moisture determination, and the Kjeldahl method was used to determine the protein content. Total lipids were determined by the Soxhlet method, and the level of cyanide was assessed by the silver nitrate volumetric method.

Results and Discussion

The rate of fermentation (development of acidity) increased with increased reduction in size of the roots. Grating enhanced contact between linamarase and linamarin so that most of the cyanogenic glucoside in the grated sample was hydrolyzed quickly to hydrocyanic acid. It also increased the surface area of the medium and made the nutrients more readily available to the microorganisms causing fermentation. In the traditional method, the roots take 4 days to soften, whereas the grated pulp ferments in about 48 h.

The microflora responsible for cassava fermentation are indigenous to the roots. Levi and Collard (1959) identified *Corynebacterium manihot* and *Geotricum candida* as the microorganisms involved in a related process — gari manufacture. Recently, Okafor (1977) questioned the validity of Levi and Collard's results, as he was unable to isolate *Corynebacterium* sp. in appreciable quantities from fermenting cassava. Consequently, Ngaba and Lee (1979) have isolated and identified *Lactobacillus* sp. and *Streptococcus* sp. as responsible for the acidity and flavour.

Because the processing of fufu involves fermenting a liquid rather than a solid, as in gari manufacture, the microflora involved are probably different. This possibility is under investigation.

In a related study, Akinrele (1964) showed that, when fresh cassava pulp was seeded with 4-day-old juice, the fermentation took 24 h. Our results confirmed this earlier work (Fig. 1). Instead of steeping whole roots in water, one could reduce process time considerably by pulping them and seeding them with 3-day-old liquor.

Drying the fufu with the laboratory oven or the Roucadil ventilated chamber proved very efficient, but the cost (Table 1) would be prohibitive for village-level processing. The simple solar/fire dryer reduced drying time to 24 h from the 72–96 h common with sun drying. It also eliminated contamination.

The product was rated very good or better (extremely good, excellent) by about 70% of the respondents from 55 households in Western Province, and more than 60% felt it was easy to prepare. Although 60% stated that the product was equal or superior to traditional fufu, 40% felt it was not white enough. Taste was judged to be the most appealing characteristic, and colour was considered the least attractive feature. The proximate analysis of improved (enriched and processed quickly) fufu showed protein 5.50%, lipids 3.30%, starch 79.6%, and soluble sugar 1.26%. The corresponding values for fufu pro-

cessed traditionally were 1.54%, 0.77%, 82% and nil. The HCN (mg/kg) was 30.7 for the improved and 19.6 for the traditional.

The time used for traditional processing of fufu was considerably reduced when the tubers were comminuted before fermentation and seeded with 3-day-old cassava liquor, and a cheap and simply constructed double-effect dryer reduced considerably the drying time. Finally, the protein content was increased substantially by supplementation with soybean flour without any significant alteration of organoleptic qualities.

This study was carried out with financial assistance from the International Foundation for Science, Stockholm, Sweden.

CASSAVA-BASED DIETS FOR RABBITS

R.T. FOMUNYAM,[1] A.A. ADEGBOLA,[2] AND O.L. OKE[2]

Rabbits, New Zealand White and Californian breeds, fed corn- or cassava-based diets had comparable reproductive, growth, and carcass traits, although feed intake and average daily gain were significantly ($P < 0.05$) greater for rabbits fed the cassava-based diets. It was more profitable to raise rabbits on cassava-based diets than on corn-based diets.

This study was carried out to investigate the effect of cassava root meal on the reproductive, growth, and carcass traits of two breeds of rabbits, New Zealand White and Californian.

MATERIALS AND METHODS

We obtained 23 New Zealand White and 23 Californian rabbits from the University of Ife and housed them in metallic cages 40 cm × 42 cm × 62 cm, raised 45 cm from the ground.

The rabbits were fed either corn- or cassava-based diets (Table 1). During the 4-week pregestation, gestation, and lactation phase of the study, 100–200 g of fresh *Stylosanthes guyanensis* was fed to the rabbits on the cassava-based diets as an additional source of protein and also as a replacement for the 8% fish meal used in the corn-based diet. Feed and water were given ad libitum.

The rabbits had 12 h daylight. The does were bred to bucks on the same diet. The rabbits were weaned at 4 weeks, and growth characteristics were measured until they were 8 weeks old. The young were fed the same diet as their does.

RESULTS

Neither breed nor diet affected gestation length, birth weights, average number born alive or dead, average weaning weight, or preweaning survival, although both breeds performed slightly better when fed the cassava diet (Table 2) than when fed the corn-based diet.

The young from does fed the cassava-based diets consumed significantly ($P < 0.05$) more feed and grew faster than did the young rabbits fed the corn-based diets. Breed did not affect feed intake or growth rate, although the New Zealand White breed gained somewhat more weight than did the Californian breed. Preweaning survival was significantly ($P < 0.05$) greater for the New Zealand White breed, 88.8%, than for the Californian breed, 66.7%.

The carcass traits of these rabbits were not affected by breed or diet, although kidneys from corn-fed rabbits were significantly ($P < 0.05$) heavier than those from cassava-fed rabbits. Similarly, the Californian breed had heavier kidneys than did the New Zealand White breed. Thyroid weight and kidney fat were not affected by diet or breed.

The cash returns possible from sales of the cassava-fed rabbits would have been greater than those from the corn-based diets. Californian rabbits fed the corn-based diet were less efficient in converting feed into meat than were the others (Table 2).

DISCUSSION

Cassava levels up to 45% have been shown to support good growth in rabbits (Eshiett et al. in press) as was shown in this study. However, the New Zealand White rabbits grew faster and utilized their feed more efficiently than did the Californian rabbits. This finding suggests that

[1] Institute of Animal Research, Mankon, Cameroon.
[2] University of Ife, Ile-Ife, Nigeria.

Table 1. Test diets supplemented with palm oil and with *S. guyanensis* fed to gestating, lactating, and growing rabbits.

	Corn-based	Cassava-based	
		Growth phase	Reproduction phase
Feed components (%)			
Guinea corn	9.87	—	—
Yellow corn	29.23	12.59	11.62
Cassava flour	—	32.41	29.92
Brewers' grains	29.23	—	—
Stylosanthes (dry-matter basis)	—	25.93	31.09
Palm-kernel meal	—	2.96	2.73
Groundnut meal	14.70	16.16	14.91
Fish meal	8.07	3.70	3.02
Palm oil	1.15	4.62	4.62
Dicalcium phosphate	2.31	0.46	0.46
Oyster shell	2.31	—	—
Mineral–vitamin premix	0.66	0.46	0.46
Amprolium (coccidiostat)	0.66	0.46	0.46
Terramycin crumble (antibiotic)	0.66	0.46	0.46
Methionine	—	0.20	0.20
Feed value			
Energy DE (kcal/kg)	3348	2716	2616
Calcium (%)	1.38	0.10	0.40
Phosphorus (%)	0.61	0.43	0.43
Methionine–cysteine (%)	0.74	0.42	0.42
Lysine (%)	1.03	0.60	0.60
Crude protein (%)	22.53	16.06	17.15
Cost (francs CFA/kg)	101	80	86

Table 2. Effects of cassava- and corn-based diets on performance of two breeds of rabbits.

	New Zealand		Californian	
	Cassava	Corn	Cassava	Corn
Reproduction				
Gestation length (days)	29.8	30.8	30.5	31.1
Birthweight (g)	49.6	44.7	47.4	48.5
Live births/doe	5.7	5.5	6.2	5.2
Weaning weight (g)	344.1	371.1	348.1	365.6
Preweaning survival (%)	74.3	61.2	71.5	63.8
Growth				
Feed intake (dry matter, g/day)	64.4	52.8	65.6	54.8
Weight gain (g/day)	22.0	15.3	16.2	16.1
Feed/gain ratio	2.9	3.4	4.0	3.4
Survival after weaning (%)	93.0	94.7	70.32	62.81
Carcass				
Slaughter weight (kg)	0.8	0.7	0.7	0.7
Yield (%)	48.8	41.0	41.0	41.0
Liver (% of slaughter weight)	3.0	3.5	3.7	3.5
Kidney (% of slaughter weight)	0.7	0.8	0.8	1.3
Kidney fat (% of kidney weight)	10.5	5.3	7.8	7.5

continued

Table 2 continued

	New Zealand		Californian	
	Cassava	Corn	Cassava	Corn
Economics				
Feed consumed (kg)	78.8	46.0	61.0	64.7
Cost of feed (francs CFA)	6304	4646	4880	6535
Body weight (kg)	0.80	0.96	0.82	0.90
Revenue (francs CFA)	49600	84480	54120	75600
Feed cost/kg weight gain	10168	10804	8793	14522

the New Zealand White is a better meat producer.

The long fibre from the *S. guyanensis* (stylo) probably enabled better utilization of the soluble cassava carbohydrates and avoided the accumulation of cecal toxins (Aitken and Wilson 1962).

The similarity for reproductive, growth, and carcass traits of the rabbits on both diets suggests that, at the levels in this study, the cyanide did not affect the rabbits or that it was rapidly detoxified by rhodanese of the liver. Rabbit liver contained 8–9 mg rhodanese/g. The value is surpassed only by the rhodanese content of rat liver, 14–28 mg/g. It is also probable that the stylo was efficient as a protein source for the support of growth and also for the supply of additional sulfur for the elimination of cyanide as thiocyanate. The utilization of stylo reduced feed cost as it replaced fish meal in the cassava diets.

The similarity in thyroid weights of the rabbits on both diets suggests that the levels of thiocyanate were below the threshold causing goitre (Oke 1973). The economic data (Table 2) show that a small farmer can produce meat for his or her table and also make money by using cassava as an energy source for rabbits. The potential, therefore, for raising rabbits for meat in the humid tropics is good, for these animals convert feed into meat more efficiently than do many other types of domestic livestock.

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EFFECTS OF CASSAVA MEAL ON THE HATCHABILITY OF CHICKEN EGGS

D.A. NGOKA, E.C. CHIKE, A.B. AWONIYI, T. ENYINNIA, AND S.O. ODURUKWE[1]

Yaffa hens and Rhode Island Red cocks were fed cassava root meal in maize-based rations at four dietary levels, substituting for maize at 0, 50, 75, and 100%; 800 eggs were collected from the hens and incubated in five replicate batches for all the treatments. The numbers of infertile eggs as well as mortality in the shell, salability, and incubation period were recorded. The eggs from the birds fed the highest level of cassava showed a significantly ($P < 0.05$) higher infertility and lower hatchability than the others. Other differences were not significant. The results suggest that cassava meal can be substituted for maize up to 75% in breeders' rations without deleterious effects on the hatchability of chicken eggs.

The use of cassava root meal as an energy substitute for maize and other cereal grains in poultry feed is becoming increasingly acceptable based on research findings. Temperton and Dudley (1941) and Fangauf (1955) reported that laying hens could tolerate substantial proportions, 40% and 25%, respectively. More recent reports have indicated no adverse effects on egg production and efficiency when cassava root meal was substituted for 50% of the cereal rations of White Leghorn pullets (Enriquez and Ross 1972). However, Ermans et al. (1973) indicated that prolonged feeding of rats on cassava depleted iodine stores markedly in the absence of iodine supplementation. They observed that thyroid dysfunction from cassava consumption was not qualitatively distinguishable from that caused by iodine insufficiency. This implies that, at high levels, cassava in feed for breeding hens would adversely affect reproduction, which is related to thyroid function (Ewing 1963). Rogler et al. (1961a,b) reported a reduction in hatchability and prolonged hatching time of eggs from hens fed iodine-deficient diets, and embryonic weight in eggs from hens fed low levels of iodine was low after 18 days of incubation. Therefore, we observed the effects of substituting cassava root meal for maize in maize-based rations, primarily focusing on the hatchability of the eggs.

[1] Federal School of Agriculture, National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

MATERIALS AND METHODS

Eighty 10-month-old Yaffa hens of similar body weight and 16 Rhode Island Red cocks were randomly selected and further randomized into four treatment groups, with four replicate groups (5 hens and 1 cock). Each group was housed in a small pen, 1.5 m × 1.2 m, under the deep-litter system of management; the percentage of cassava substituting for maize in maize-based rations was 0, 50, 75, and 100. Water and feed were fed ad libitum.

The meal was prepared with 12-month-old cassava roots, variety TMX 30011. The unpeeled roots were washed immediately after harvest, cut in bits, and dried in a tropical dryer for 3 days. The rations were formulated at nutrient levels recommended by the US National Research Council (NRC 1977) for poultry breeders and layers.

All four diets were isonitrogenous and isocaloric with iodine supplementation (Table 1). The dietary composition was about 2850 kcal/kg, the composition being about 16% protein, 0.8% lysine, 0.4% methionine, 0.5% methionine and cystine, and 3.7% calcium. The cassava root meal contained 28.0 mg/kg hydrocyanic acid, 2.4% crude protein, 0.9% crude fat, and 3.1% crude fibre. Moisture content was 8%. A total 800 eggs were selected and incubated in five batches in a Funki Hammerum cabinet incubator. Eggs were examined after 18 days of incubation for infertility. Dead-in-shell; hatchability (number hatched from number set); sal-

Table 1. Ingredients (%) in experimental feed.

	% cassava substitution for maize			
	0	100	75	50
Cassava	—	44.00	33.93	26.03
Yellow maize	64.27	—	12.92	29.68
Groundnut cake	7.00	8.50	8.00	7.00
Palm kernel meal	10.00	27.42	26.36	17.12
Fishmeal	8.00	9.00	9.00	10.00
Bonemeal	1.00	1.00	1.00	1.00
Oystershell	8.00	7.78	7.00	8.00
Palm oil	0.73	1.30	0.79	0.17
Salt	0.40	0.40	0.40	0.40
Vitamin premix[a]	0.50	0.50	0.50	0.50
Mineral premix[b]	0.05	0.05	0.05	0.05
Methionine	0.05	0.05	0.05	0.05

[a]Vitamin premix provides (per kg of feed): vitamin A, 8000 IU; vitamin D_3, 1400 IU; vitamin E, 3.0 IU; riboflavin, 3.0 mg; pantothenic acid, 3.0 mg; nicotinic acid, 10.0 mg; vitamin B_{12}, 0.008 mg; vitamin K, 2.0 mg.

[b]Mineral premix provides (per kg of feed): choline chloride, 400 mg; ethoxyquin, 125 mg; iron, 25 mg; manganese, 80 mg; zinc, 50 mg; copper, 2.0 mg; cobalt, 0.2 mg; iodine, 1.2 mg.

Table 2. Effects of graded levels of cassava root meal on the hatchability of chicken eggs.[a]

	Substitution of cassava for maize (%)				Standard error
	0	100	75	50	
Infertility (%)	19.0a	28.0b	7.0a	15.0a	8.11
Mortality in the shell (%)	4.0a	10.5a	15.5a	9.5a	—
Salable (%)	72.0a	59.0a	74.5a	73.0a	—
Unsalable (%)	3.7a	2.6a	3.9a	4.0a	—
Hatching (%)	77.0a	61.5b	77.5a	76.0a	10.2

[a]Values within the same row not sharing a common letter are significantly different ($P < 0.05$).

ability; and incubation duration (days) were measured at hatching. All data were statistically analyzed, and mean differences were determined by the least significant difference method.

Results and Discussion

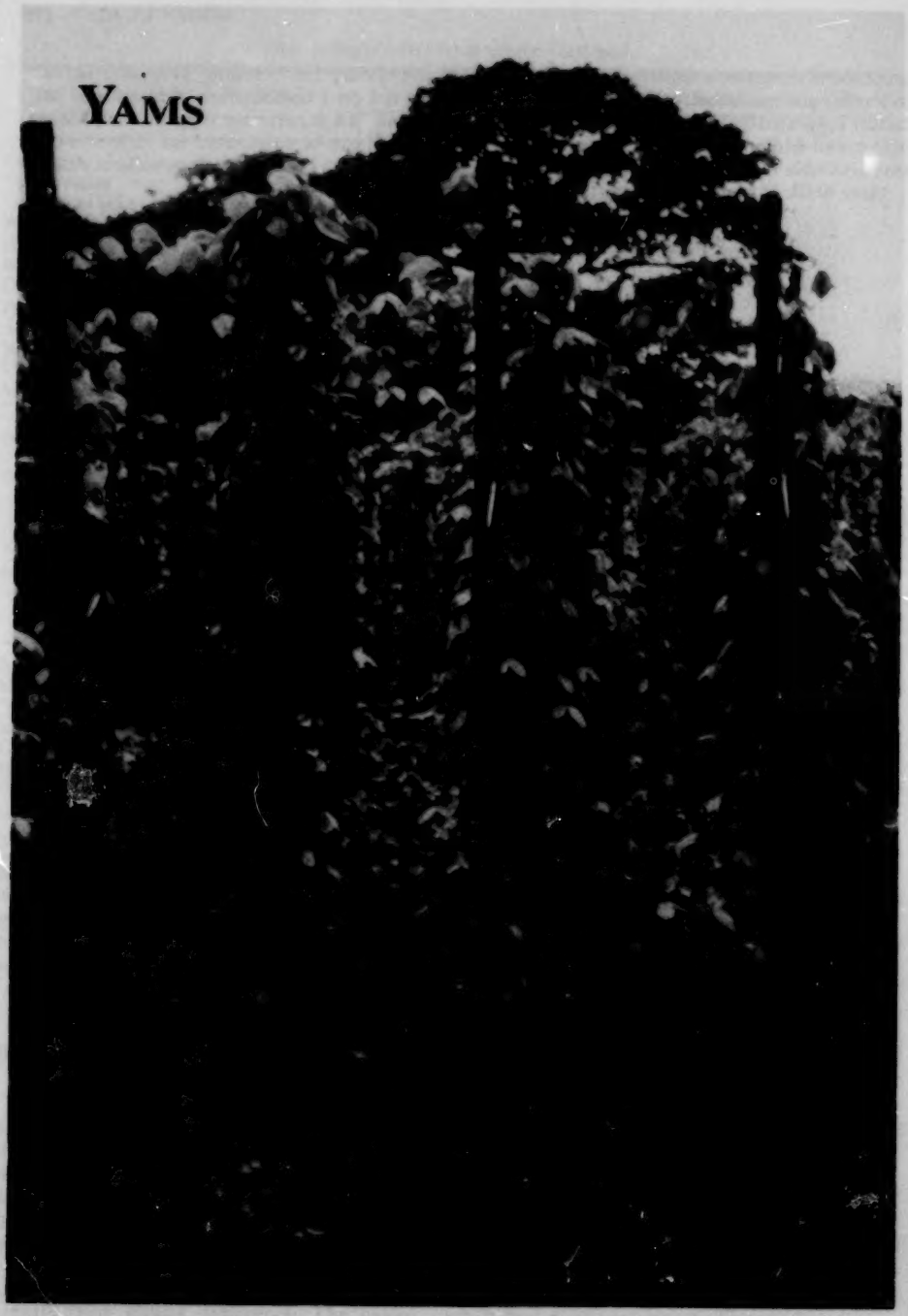
The eggs from birds fed the highest level of cassava showed significantly ($P < 0.05$) higher infertility and lower hatchability than did the others. There were no significant differences in the percentages for mortality in the shell or salability, and the hatching time was not prolonged for any of the treatments (Table 2).

The results of this experiment indicate that the cassava meal affected hatchability of eggs differently from iodine deficiency. The lower hatchability and higher infertility observed at 100% substitution of cassava for maize meal were the only significant differences between treatments. The weights of the day-old chicks were not unusual. These findings, therefore, do not support Omole's (1977) speculation that high levels of cassava would delay hatching time.

The high infertility and low hatchability values observed at 100% cassava substitution for maize may reflect insufficient methionine and B_{12} (in the form of hydroxocobalamin) known to detoxify HCN and to break down cyanocobalamin (vitamin B_{12}), which is important to hatchability in laying hens (Ewing 1963). Also, the diet in which cassava substituted for all the maize would have been higher in HCN than the other treatments, and HCN's affinity for metal ions may have rendered both copper and iron unavailable (Omole 1977). HCN combining with hemoglobin forms cyanohemoglobin, which does not carry oxygen. The resulting low oxygen supply to the shell gland disrupts the

secretion of inorganic materials that may be vital to fertility and hatchability (Omole 1977). Other factors suggested by Morrison and Sarett (1958), Miller and Miller (1962), and Edwards (1967) may also have been operating.

More work is required to ascertain nutrient requirements for breeding hens and service cocks fed on a combination of maize and cassava, but this experiment suggests that cassava root meal can be substituted for 75% of maize meal in poultry breeders' rations without deleterious effects.


YAMS

IN-VITRO CULTURE OF *DIOSCOREA ROTUNDATA* EMBRYOS

C.E.A. OKEZIE, F.I.O. NWOKE, AND S.N.C. OKONKWO[1]

Dioscorea rotundata (Obiaoturugo variety) embryos were found to germinate faster in Murashige/Skoog (1962) and Linsmaier/Skoog (1965) media than if left in intact seeds. The ability of the embryos to germinate in the two media increased with time from seed harvest — an indication that recovery of seeds from dormancy is gradual and that the embryos are immature at the time of seed harvest. The latter is further supported by the embryo's gradual increase in size and transformation from globular to fan-shaped during the 3–4 month dormancy. The technique used in this study could enhance breeding programs.

Wilson (1978) reported that the development of methods for producing yam seeds and growing large populations of white yam (*Dioscorea rotundata*) seedlings opens the way for the traditional approach to breeding for crop improvements.

Tissue culture in yam propagation, though still in its infancy, has permitted plantlet formation from yam tuber blocks (IITA 1973), from nodal sections of young yam shoots (IITA 1974), from nodes and shoot meristems of *D. rotundata* (IITA 1977), from single node cuttings of *D. alata* (IITA 1980), and from embryos of *D. rotundata* (Okezie 1981). Perfection of this technique will not only provide the quickest mode of multiplying improved cultivars in a disease-free form (IITA 1977) but will also aid tremendously in generating uniform plantlets that will reveal attributes of the growth characteristics that could be exploited in a breeding program.

This paper reports on the possibility of raising plantlets from *D. rotundata* embryos in vitro on both Murashige/Skoog (1962) and Linsmaier/Skoog (1965) media even without hormonal additives. It also speculates on the potentials of this in-vitro system in yam improvement.

MATERIALS AND METHODS

The embryos were derived from seeds of *D. rotundata* (Obiaoturugo variety) fruits harvested from experimental farms of the National Root Crops Research Institute, Umudike, in October 1981 at the end of the yam-growing season.

The seeds were surface-sterilized in 1% sodium hypochlorite solution for 10 minutes and rinsed in four changes of sterile, distilled water. The embryos were extracted and inoculated in 20-mL portions of 1% (10 g/L) sterile Difco-Bacto agar slants in two media without hormonal additives, namely modified Murashige and Skoog (1962) basal medium and modified Linsmaier and Skoog (1965) medium. Sucrose (3%, 30 g/L) was used as a carbon source for the growth of the embryos, and the pH of the media was adjusted to between 5.5 and 5.8. Before inoculating with the embryos, we autoclaved the media. Inoculation was done in a sterile environment (ultraviolet radiation for 30 minutes). One embryo was inoculated into each culture tube, and there were 25–30 tubes/treatment. Surface-sterilized intact seeds were also planted in 20-mL portions of 1% Difco-Bacto agar slants to serve as controls. The tubes were kept in a dark incubator at 27 ± 1°C.

In one study, seeds were dewinged and stored in a desiccator for 4 months to ensure complete breakage of dormancy.

In a second study, the fruits were still green on the plant, and germination studies on the embryos were started immediately. The fruits were spread out to dry in the sun and the embryos were extracted monthly for serial germination tests. The tests lasted 4 months. The embryos and seeds were allowed to grow in the media for a total of 50 days.

In the third study, some seeds were soaked in

[1] Department of Botany, University of Nigeria, Nsukka, Nigeria.

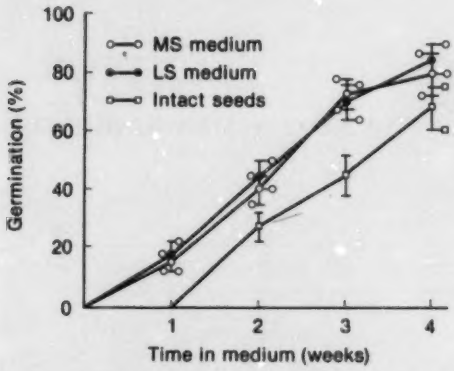


Fig. 1. *Germination (%) of* Dioscorea rotundata *seeds compared with embryos in modified Murashige/Skoog and Linsmaier/Skoog media without hormonal additives.*

water for 24 h and carefully dissected. The embryos — 40–50 monthly for 6 months — were extracted and mounted on a slide. Length and breadth were measured by means of a calibrated ocular micrometer (Erma Optical Works Limited, Japan). Also, the excised embryos were assessed for their shapes and categorized as globular or fan-shaped and the percentage of each recorded.

Results

Both Murashige/Skoog and Linsmaier/Skoog media without hormonal additives supported the germination of *D. rotundata* embryos (Fig. 1). Although there was no significant difference in the extent to which the two media induced germination, both supported more germination than did intact seeds (control) within the first 3 weeks of treatment. By the 4th week, only Linsmaier/Skoog medium induced a significantly higher percentage of the embryos than did intact seeds (control).

The number of days to first germination and 50% germination for Linsmaier/Skoog medium, Murashige/Skoog medium, and intact seeds (control), respectively, was 5, 15; 6, 17; and 11, 24, both media inducing germination much faster than intact seeds.

Neither of the two media nor intact seeds (control) could support embryo germination immediately after fruit harvest at the end of the growing season (Table 1). Intact seeds could not even germinate after 1 month from fruit harvest, although both Murashige/Skoog and Linsmaier/Skoog media stimulated germination of some excised embryos. Whereas it took 33 days to notice germination under Linsmaier/Skoog medium, it took 39 days to notice it in Murashige/Skoog medium, with percentage germination also being higher in the former than in the latter. None of the media could support up to 50% germination of embryos within the 1st month. The potential for germination increased with time after harvest.

There was progressive growth of the embryos in length and breadth within the seed after har-

Table 1. Effects of modified Murashige/Skoog (MS) and Linsmaier/Skoog (LS) media without hormonal additives on the germination of developing *D. rotundata* embryos.

Age (months) of embryos from time of first harvest	Treatment given to embryos	Days to first germination	Days to 50% germination	Germination after 4 weeks (%)
0	MS medium	—	—	0
	LS medium	—	—	0
	Intact seeds	—	—	0
1	MS medium	39	—	10.5
	LS medium	33	—	12.5
	Intact seeds	—	—	0
2	MS medium	23	33	40
	LS medium	18	30	45
	Intact seeds	29	39	25
3	MS medium	10	18	70
	LS medium	8	14	70
	Intact seeds	14	24	60
4	MS medium	6	15	80
	LS medium	5	11	85
	Intact seeds	12	20	65

Table 2. Sizes of *D. rotundata* embryos in course of postharvest development.

Time (months) from fruit harvest	Size of embryo		Globular embryos (%)	Fan-shaped embryos (%)
	Length (μm)	Breadth (μm)		
0	685	537	83	17
1	892	624	64	36
2	973	715	52	48
3	1066	787	44	56
4	1090	820	38	62
5	1105	820	32	68
6	1115	822	29	71

vest (Table 2). This increase did not continue beyond the first 6 months from harvest. At harvest, the embryos were mostly globular, but, with time, more than 70% became fan-shaped, reflecting growth of the cotyledon.

Discussion

Both modified Murashige/Skoog and Linsmaier/Skoog media were superior to the natural constituents of the seed endosperm in stimulating the germination of nondormant, viable *D. rotundata* embryos, even in the absence of hormonal additives. Modified Murashige/Skoog medium reduced the germination time by 5 days, and modified Linsmaier/Skoog medium reduced it by 6 days.

In-vitro embryo culture eliminates the constraints of seed germination (embryo growth and emergence of radicle) caused by the seed coat or the endosperm.

Waitt (1959) suggested that seeds contain rudimentary embryos at the time of harvest and that a period of drying permits the embryos to mature and thus ensures germination. In a review of sexual propagation for yam improvement, Sadik (1976) stated that other difficulties in seed germination had masked the 3–4 month dormancy. One of us (Okezie 1981) showed through serial germination of both intact seeds and excised embryos that dormancy in Obiaoturugo variety is completely broken by about 14 weeks after harvest. The present study has shown that intact seeds were not capable of germinating within 1 month of harvest, although modified Murashige/Skoog and Linsmaier/Skoog media were able to induce germination of up to 10.5% and 12.5% of embryos, respectively. This suggests that dormancy can be broken through embryo culture even within the 1st month from harvest. The progressive increase in the ability of both excised embryos and intact seeds to germinate suggests that recovery from seed dormancy is gradual, not spontaneous. The exact mechanism of recovery from dormancy is not known, but the embryo seems to acquire factors from the endosperm for 3–4 months from harvest.

The in-vitro system described in this paper provides a level of experimental flexibility not easily attained through the use of seed or seed tubers in the propagation of yams. With the efficient development of embryo culture, greatly increased rates of multiplication can be achieved. This technique could also be exploited in generating uniform clonal materials for both initiating a viable breeding program and providing materials for experimental work. Tissue culture is also a means for developing long-term storage of germ plasm and rapid multiplication of improved cultivars in disease- and insect-free form to meet the demands of national programs anywhere in the world (IITA 1977; Henshaw 1979).

Embryo culture could be used to circumvent postfertilization barriers to sexual hybridization. This has been achieved in *Coffea canephore* and *C. dewevri* in modified Heller medium without hormones and *C. arabica* in Linsmaier and Skoog medium (Monaco et al. 1977).

Immature embryos of *D. rotundata*, which would be aborted if allowed to develop in the seed through the 3–4 month dormancy, could be made to germinate in vitro in a properly formulated medium. Some measure of success in this direction has been reported (Okezie 1981) for *D. rotundata* embryos that were cultured 2 weeks from seed harvest. Similar findings have been reported on embryo axis of *Phaseolus vulgaris* (Crocomo 1981) for avoiding seed abortion from interspecific crosses and on coconut embryo (De Guzman 1980) for propagating a nongerminating type of coconut known locally as makepuno. Jagannathan (1980) also used in-

vitro culture for the growth of immature *Carica papaya* embryos, which usually abort if allowed to mature on the pod.

Both in-vitro embryo culture and fertilization have potential to overcome hybridization barriers between species and possibly genera. Techniques are already well established and have been successfully applied in several species including wheat and barley (Nabors 1980) and *C. arabica* (Walyaro and Van der Vorsen 1977). This technique could be borrowed for *D. rotundata* and could even permit hybridization with other species.

ECONOMIC INDICES FOR CLONAL SELECTION AND BREEDING OF YAMS

O.O. OKOLI, J.U. NWOKOYE, AND C.C. UDUGWU[1]

Edible yams are widely grown under mixed-cropping systems in Nigeria. Sizable portions of food tubers are planted to produce new crops, the yields of which are greatly influenced by the numbers and sizes of seeds planted. Currently, yield data are not reported in such a way as to take this variation into account. Thus, we have developed a system of reporting that will enable a better comparison of results. We also have detailed other indices that make for objective selection of clones in a breeding program and, to exemplify the approach, we have used these indices and other conventional descriptors to describe cultivars belonging to two yam species.

Now that yams, especially the *Dioscorea rotundata–D. cayenensis* complex, *D. dumetorum*, and *D. alata*, have been successfully grown from true seeds (Okoli 1975; Sadik and Okereke 1975), breeders will be perfecting the operation so that they can select and improve the varieties. This means that the traits to be transferred or eliminated must be clearly defined not only taxonomically (Waitt 1961; Ukoha and Ikediobi 1983) but also economically. We have empirically defined phenotypic expression of economic attributes in an attempt to provide indices for use by breeders to rank selective value among yam cultivars.

More than 4000 clones of six species of *Dioscorea* were collected during surveys in Nigeria. The clones are being maintained in the germplasm plots at the National Root Crops Research Institute (NRCRI); from records of vegetative, floral, and tuber characteristics over a 6-year period, we evaluated four clones of white yams (*D. rotundata*) and one of water yam (*D. alata*) for descriptive characteristics that may be used as standards for selection in yam breeding.

CHARACTERIZATION

Some of the characters that lend themselves to improvement by breeders are yield, shape, flowering, time to maturity, dormancy, storability, and food quality.

Yield is usually the weight of fresh or dry tubers. However, the yield is influenced by the number and weight of the tubers used as seeds (the setts). Up to 4 t/ha may be used, and, generally, the larger the seed tuber, the larger the yield expected. Comparison of yields from different locations and times is difficult because the amount of seed material used is neither standard nor stated. Also, the yield data do not show what fraction (yield minus seeds for the next planting) is available to the farmer for sale or for food. Yield data can be made comparable by the use of a seed-yield factor — W_h/W_p — where W_h is weight of tubers harvested and W_p is weight planted. The result is the number of times the amount of yams used in planting ("seed") is multiplied in the harvest. Thus, if a farmer uses 3 t/ha and harvests 12 t, the seed-yield factor is 4. The amount of yield available to the farmer is not 12 t; if he or she needs 3 t for establishing next year's crop, then the available harvest (for sale or eating) is 12 – 3 – 3 t or 6 t. To determine what fraction of the yield is available to the farmer, we express the available harvest as a percentage of the total yield. Thus, available yield (%) = $(W_h - 2W_p)/W_h \times 100$.

This means that only 50% of the total harvest of 12 t/ha would be available to the farmer. Seed-yield factor takes into account the (genetic) yield potential of the variety as well as the relationship between the amount of seed tubers planted and the yield obtained — a relationship that varies among varieties and between species. Available yield percentage indicates the profitability (or otherwise) of growing a particular yam cultivar.

The shape of the tubers, although sometimes affected by environment (soil density, presence

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

or absence of rocks, roots, etc. in the soil), is primarily specific to the variety. The commonest shapes include wedge-like (large head and thin tail); cylindrical (fairly uniform from head to bottom); and fan-like (flat and spreading bottom). We defined the shape index as the ratio of the length to the girth of the tuber, with the average girth being used in calculations. Shape index reflects the eye appeal and acceptability of the tuber. An index of 1–2 is most acceptable to consumers in Nigeria; yams with a shape index of 1 or less are likely to be suitable for mechanized harvesting.

In the germ-plasm plots at NRCRI, the plants are observed for appearance of flowers over a number of years. Records are also kept of the type of flowers seen — staminate (male) or pistillate (female) or both — and of how soon (days) after planting the flowers appear. Fewer than 60 days from planting to flowering is classified as early; 61–90 days, medium; and more than 90 days, late.

This record is important for clones to be used in a hybridization program, as the flowering times of the staminate and pistillate plants need to be synchronized. The pistillate flowers remain open for 1 day only.

In yams, the plants are mature when the foliage and vines begin to die naturally (as opposed to death caused by diseases, pests, environmental changes, etc.). For practical application, maturity is the time from planting to normal dieback. Cultivars that mature 5–7 months after planting are rated as early; 8–9 months, medium; and longer than 9 months, late.

Yam growth is a continuum whether in the field or in storage (Okoli 1980). However, in practice, the period from harvest to sprouting is usually regarded as dormancy. Dormancy for fewer than 30 days is regarded as short; 31–45 days, medium; and more than 45 days, long.

Storability is the keeping quality of healthy, uninjured yam tubers under normal storage conditions (open, well-ventilated racks under heavy shade). Many factors affect the storability of yam tubers. For instance, the presence of rotting tubers near healthy ones may shorten storability of the healthy ones. Similarly, storage temperature and humidity may affect such physiologic activities as respiration and sprouting, and these in turn will affect storability. Storability as assessed here for the time being is subjective, as storage conditions are fairly difficult to replicate.

Assessments of food quality include cooking time, colour, appearance, texture, and taste. The time (in minutes) it takes a 1-cm-thick slice taken from the middle of the tuber and immersed in boiling water to cook — the cooking time — varies from 5 minutes in some cultivars of *D. rotundata* to 360 minutes in some cultivars of *D. dumetorum*. White flesh and a smooth appearance are preferred to a yellowish-white and grainy appearance. Yams that turn brown when cut and exposed to air are considered poor. The texture and elasticity of pounded yam is particularly important in Nigeria. Yams that can be pounded into a smooth, elastic dough are judged to be good, whereas those with a rough, brittle dough are poor. The texture and taste of boiled yams may be friable and sweet or starchy and bland. In other words, consumer preferences and local practices are a guide to appropriate food quality. At NRCRI, food quality is rated on a scale of 1–5.

Examples

Within the species of the genus *Dioscorea*, there are groups of cultivars whose differences are not enough to make them separate varieties. Thus, we have described four such groups for *D. rotundata* and one for *D. alata* to exemplify the use of criteria for selection.

D. rotundata

Nwapoko tubers are generally large, long, and often mildly pointed at one end. The shape is often spindular, with a shape index between 2 and 3. Tuber branching or indentation is not common. Skin is firm and light-coloured with a few roots on the surface that give it a rough texture. Few lenticels are visible, and the roots on the head are spiky. The cortex is greenish, and the flesh milky white. Nwapoko rarely flowers under Umudike conditions; when it does, only staminate flowers are produced. Its yield is relatively low to moderate. A mean yield of 0.7 kg/plant and 1.7 tubers/stand is normal. The seed-yield factor is about 1.33 for ware yams and 2.56 for seed yams. Available yield % is about −50 for ware yams and 22 for seed yams. It stores well in cool, airy rooms. Cooking time is 6 minutes, and Nwapoko can be pounded into good fufu. Food quality rates 4.5 out of 5. It is susceptible to wilt, leaf spot, anthracnose, and shoestring virus. Termite and beetle damage depends on where the yam is planted, and both root knot and crack-forming nematodes may attack the tubers. Rotting in the field is rare. Other local names include Adaka, Agba, Ig-

By defining the characters of existing cultivars carefully, breeders can focus on selecting the most socioeconomically desirable ones.

uma, Igum, Aga, Akuru, Agbakuru (Igbo), Agboja (Ugep), Nkara, Mkpidot, Okot (Efik), Akpochi, Ogbagu, Gbangu (Tiv), and Ebo (Ogoja).

Abi includes cultivars that produce long tubers (shape index between 2 and 3, e.g., Abi Ogologo) and squat tubers (with a shape index less than 1, e.g., Abi Ito). Branching or flattening of the tail of the tuber is common, and the bottom is mildly pointed. Unlike Nwapoko, the roots on the head of Abi are not usually spiky. The skin of the tuber is light-coloured and smooth (usually no roots are found on the body) and often peels in storage. Lenticels are not easily visible. The cortex is greenish, and the flesh is greenish-white. Abi usually flowers early, producing staminates, and is early maturing. Tuber yield is moderate to high, even on poor, sandy soils. Average yield/stand is 0.75 kg; tubers/plant, 1.43; and average tuber weight, 0.5 kg. Seed-yield factor is about 2.96 for seed yams and 1.75 for ware yams. Available yield % is about 32 for seed yams and −14 for ware yams. Abi keeps well in open airy places, although its dormancy is short. Its food quality rates 3, but it improves with storage. Pounded Abi is regarded as poor because it is sticky. The cultivars within this group are fairly resistant to most foliage and tuber diseases: not affected by anthracnose, wilt, or virus, although they are susceptible to nematode attack. Other local names include Ngarada, Orume, Nkoroto (Igbo), Nkorito, and Okperekpere (Efik).

The Okwocha group produces medium to large tubers that are blocky, with shape index less than 1. The bottom is often rounded, and the head, flat or square with unspiked roots. Indentations are common on the tubers. The skin is firm, light-coloured, but very rough because of the many roots on it. Few lenticels can be seen. The cortex is greenish, and the flesh is milky white. Okwocha flowers easily, although late, producing only staminate flowers. Its tuber yield is moderate to high. Yield/plant is 0.79 kg, tubers/plant 1.67, and average tuber weight 0.47 kg, with available yield % being 41 for seed yams and 3 for ware yams. The seed-yield factor is 3.39 for seed yams and 2.07 for ware yams. It is medium to late maturing and does not store well, rotting fairly quickly in high humidity. Nevertheless, its dormancy is moderately long. It rates well in food quality, having a score of 4. It does not pound well, as it tends to be friable, but its taste offsets this drawback. It is susceptible to leaf spot, wilt, anthracnose, and shoestring virus as well as to rots in the field and in storage. Damage by termites, beetles, and nematodes is also almost always present. Other local names include Awudu, Omashi, Evo (Igbo), Adasu, Ntume, and Dan anacha (Tiv).

Obiaoturugo produces large cylindrical tubers with a shape index between 1 and 2. The bottom end is often rounded, and the head flat or square with roots that have no spikes on them. The skin is firm, light-coloured, and smooth (no roots on the body). Few lenticels can be seen. The cortex is greenish, and the flesh is milky white. Obiaoturugo flowers sparsely or profusely depending probably on weather conditions. It flowers late and produces mostly pistillate inflorescences, although it may produce both pistillate and staminate florets on the same spike. The ovary later develops into a 3-sided capsule containing 2–6 winged seeds. Its tuber yield is low to moderate: average yield/stand 0.76 kg, tubers/plant 1.23, and tuber weight 0.62 kg. Seed-yield factor is about 3.14 for seed yams and 1.37 for ware yams; available yield % is about 36 for seed yams and −46 for ware yams. It is medium to late maturing and keeps moderately well in cool, dry, airy rooms. Its food quality is 4.5. Cooking time is 6 minutes, and the tuber can be pounded into good fufu. It is susceptible to anthracnose and leaf spot and is sometimes liable to beetle and termite attack. Nematode attack is rare, but preharvest rot is usually present, especially if harvesting is delayed. Other local names for Obiaoturugo are Iyawo (Yoruba), Oyoyo (Idoma), Ewesu, Elewusu (Kwara), Igoyo, Tameneyo, Yatoho Tsatoho (Tiv), Unegbe (Igbo).

D. ALATA

Tubers of *D. alata* variety UM680 are usually large, long, and pointed at the bottom. They are spindular, with a shape index between 2 and 3. Their body has shallow grooves and a few roots, which make it rough to the touch. The skin is firm, and light brown. The cortex is reddish, and the flesh purplish-white. No flowering has been observed for this cultivar in Umudike. It is late to mature, with a moderately high yield: 1.39 kg/plant, 1.52 tubers/plant, and 0.92 kg/tuber. Seed-yield factor is about 5.72 for seed yams and 2.61 for ware yams, with the available yield % being about 65 for seed yams and 23 for ware yams. It stores very well in cool, airy rooms. Its cooking time is 7 minutes, but it is not well accepted by consumers. Pounded, it is considered poor, and the food quality rating is 3. It is tolerant to anthracnose–blotch, leaf spot, and shoestring virus.

SEED-YAM PRODUCTION

M.N. ALVAREZ AND S.K. HAHN[1]

We tested several techniques to increase the multiplication ratio in yams, and all showed promise, although the degree varied according to cultivar. Seed-yam production from true seed gave the highest yield per unit area. The use of microsett propagation with the aid of phytohormones increased the multiplication ratio from the traditional 1 : 4 to 1 : 90, and the minisett technique with plastic mulch showed the greatest potential for rapid multiplication at the farm level. Plastic mulch had no adverse effect on the seed yams produced.

White-yam (*Dioscorea rotundata*) production in West Africa has been declining partly because of the scarcity of planting material, which is also the source of food, the underground tuber. The ware-yam producer can obtain planting material by "topping" or milking (Okigbo and Ibe 1973), cutting ware yams into setts, "junking" (cutting the yam head) (Ferguson 1980), or from specially grown yams called seed yams.

The seed yam is merely a small tuber (300–1000 g) with remarkable flexibility and storability under ambient conditions. Although there are many environmental factors affecting performance of yam setts in the soil, the seed yam has performed reliably in a wide range of conditions.

There are many ware-yam producers, but seed-yam production is specialized, labour-intensive, and costly. A yam-based, farming-system survey conducted in three villages in the humid tropics of southern Nigeria revealed that only one village was growing seed yam as a major enterprise (Bachmann 1981). The reduced availability of seed yams has become a major constraint in many ware-yam-producing areas (Bachmann and Winch 1979; Diehl and Winch 1979; Bachmann 1981), with some ware-yam farmers being forced to reduce output or stop production.

Interviews with seed-yam producers disclosed that their major constraint to expansion was labour input. Others have also observed that one of the most serious problems encountered in yam production is the labour requirement.

Several efforts have been initiated to reduce labour cost and inputs in ware-yam production (Okigbo and Ibe 1973; Ferguson 1980). Although the limited supply and the high cost of seed yams are major constraints in yam production (Akoroda 1982), only limited efforts have been made to increase the efficiency and reduce the costs of seed-yam production by the farmer (Akoroda and Okonmah 1982; Okoli et al. 1982).

The objectives of our experiments were to assess the potential of white-yam clones to produce seed-yam-sized tubers from presprouted minisetts and microsetts; to investigate the possibility of improving germination of minisetts by suberization; to determine what inputs of traditional seed-yam production could be modified or replaced (staking, weeding); and to evaluate the potential of seed-yam production from true seeds.

MATERIALS AND METHODS

For propagation from true seeds, selected breeding lines were direct seeded and transplanted to seed beds, prepared with topsoil and compost and lightly shaded with palm leaves. The seeds were treated with a fungicide–insecticide combination and sown 15 cm apart in rows 30 cm apart. The beds were then mulched with rice hull or sawdust. When the vines developed, they were trained on string supported by frames erected over the nursery bed. Tubers were harvested 9 months later.

In a preliminary micropropagation trial, *D.*

[1] International Institute of Tropical Agriculture, Ibadan, Nigeria.

rotundata (cv. TDrs 4001-C226) and *D. alata* (cv. TDa 291) were used as source material. Tubers, ca 500 g each, were cut into small pieces (3–5 g each); 80 pieces were used/treatment. Some pieces served as a control; others were dipped in one of five treatments: naphthalene-acetic acid (NAA) at 500 and 1000 mg/L, 6 benzylamino purine (BA) at 500 mg/L alone, and in combination with the two concentrations of NAA. All the pieces were dusted with Aldrex T and planted in moist, medium-grade vermiculite in jiffypots 6 cm × 6 cm. These were watered as was necessary. After 43–45 days, the number of roots on each section was counted; mean length of roots and percent survival were observed.

Large-scale micropropagation was the next step. Foam trays 66 cm × 40 cm, with cone-shaped compartments, 3.8 cm × 3.8 cm, were used, and the compartments were filled with medium — equal portions of sawdust, medium-grain vermiculite, and soil. Tuber pieces (3–5 g) were dipped in 100 ppm NAA, planted in the compartments, and kept in a propagation house and watered when necessary. As growth started, the plantlets were transferred to partial shade for hardening and, after 5 days, were transplanted to the field on ridges covered with plastic mulch.

For the presprouting minisett trial, two *D. rotundata* clones were cut (NRCRI 1980a; Okoli et al. 1982), into half-moons (45–60 g), placed on sand beds, and sprayed with Captan (2.5 g/L). These minisetts were covered with plastic for suberization for 1–2 days before being covered with a 2-cm layer of river sand and palm leaves. Three weeks later, the pieces were transplanted to the field, at a spacing of 0.5 m × 1 m. Seven months later, the field plantings were harvested.

In experiments to determine substitutes for the costly inputs of traditional yam production, *D. rotundata* (cv. Abi and Nwapoko) tubers were cut into pieces (100–150 g), treated with ash, and allowed to dry before being planted. The sites were plowed and ridged (1 m apart) by conventional methods, and the setts planted 50 cm apart in rows, with 240 setts/plot in three replications. One treatment (in 1981) was traditional, exemplifying the cultural practices employed by Nigerian farmers. A second included a modified staking system (arched PVC pipes, 1.27 cm, supporting plastic mesh at 0.75–1 m aboveground), supplemented by preemergent herbicide (a mixture of Cotoran and Dual, 2 g a.i./ha, each, immediately after planting). In a third treatment, the herbicide replaced staking and, in a fourth treatment, black and white polyethylene strips were placed on the plot after germination to serve as mulch. This treatment was unreplicated.

The soil temperature and moisture were monitored toward the end of the rainy season until harvest. Soil thermometers (mercury-in-glass) were installed in one replicate for each treatment 5 cm deep on the crest of the ridges. Readings were taken at 0900 h and 1400 h. Soil-moisture samples were taken from four locations in each of the mulched and unmulched plots and expressed as percent on an oven-dry basis.

Soil samples were also taken for nematode population determination at the time of harvest.

Results and Discussion

The production of marketable seed yams from true seeds was as high as 42 t/ha (Table 1), with the tubers ranging in weight from 100 g to 1200 g. Yield was up to 2.5 times that expected from traditional methods. The promising families are also responding positively to dense plantings, which produce a canopy early and reduce the weed problem. This system has exhibited tremendous productivity on a per-unit-area basis. Tuber size, uniformity, and suitability for rapid, efficient hand harvesting are excellent, although the potential for adapting this system to farm or commercial production has not been evaluated.

In the preliminary micropropagation trial, both concentrations of NAA greatly increased the percentage of surviving *D. rotundata* that rooted but not *D. alata* (Table 2). BA at 500 mg/L reduced percent survival, total number and length of roots in white yam but not in *D. alata*. In water yam, the untreated pieces rooted and sprouted the earliest (about 28 days after planting) and those treated with the NAA–BA combination at 1000 and 500 mg/L had poorest root formation (Fig. 1).

Table 1. Seed-yam yield and percent of total tubers of four promising yam families and one check grown from true seeds in well-prepared seed beds.

Family	Marketable seed-yam yield	
	t/ha	% of total tubers
W 370	42	70
W 33	27	50
W 56	22	45
W 71	18	30
Okumodu (check)	15	25

Table 2. Percent survival and rooting of *Dioscorea alata* and *D. rotundata* yam pieces after NAA and BA dips and 5 weeks of growth in vermiculite.

Treatment concentration (mg/L)		Survival (%)		Survivals rooted (%)	
NAA	BA	TDa 291	TDrs 4001-C226	TDa 291	TDrs 4001-C226
0	0	60	90	69	60
500	0	93	100	71	100
1000	0	93	97	56	92
0	500	83	56	46	28
500	500	63	80	51	71
1000	500	93	90	8	93

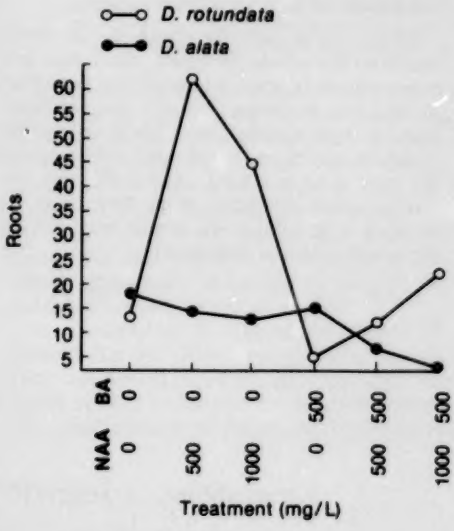


Fig. 1. *Effect of phytohormones (NAA and BA) on rooting of microsetts of* D. rotundata *and* D. alata *yams.*

Table 3. Comparison of herbicide and no staking, herbicide and modified staking, and plastic mulch with traditional practices of seed-yam production.

Treatment	Yield (t/ha)
Abi	
Herbicide, modified staking	14
Herbicide, no staking[a]	16
Traditional	10
Nwapoko (check)	
Herbicide, modified staking	10
Herbicide, no staking	3
Plastic mulch	10

[a]Resulted in benefit of more than $2000/ha.

Results for root length followed a similar trend. For large-scale propagation under Ibadan conditions, the best planting time would be May–June. In our studies, transplanting of hardened plants in the field resulted in good establishment (90%) quickly followed by new growth.

Mean tuber yield in the presprouting minisetts was 400 g, with a range 80–1252 g. These results demonstrate that some lines have very strong sink or good bulking ability — a character

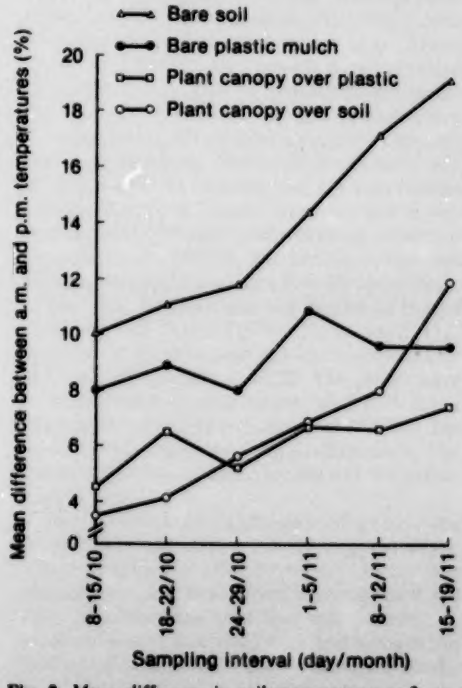


Fig. 2. *Mean difference in soil temperatures at 5 cm deep between 0900 h and 1400 h.*

that may be important for efficiency in seed-yam production from minisetts.

In the studies with Cotoran and Dual as a preemergence herbicide, the control plots required a minimum three weedings, whereas the herbicide-treated plots were sprayed once and weeded once by hand. The herbicide had no noticeable phytotoxic effect on the plants.

The yield from herbicide-treated plots was not statistically different from hand-weeded plots (Table 3). The yield (3 t/ha) of the check cultivar, Nwapoko, with herbicide and no staking was lowest, whereas this treatment gave the highest yield (16 t/ha) for Abi. Abi, a vigorous starter, was able to establish a canopy after one weeding. Besides early establishment, Abi showed resistance to virus and other field diseases.

The modified staking allowed the plants to form a canopy that subsequently suppressed weeds. The PVC pipes and plastic mesh provided good material for stakes, being undamaged by termites and reusable, unlike bamboo stakes.

The use of the plastic-strip mulch gave good weed control and did not adversely affect the plants. At 5 cm deep, bare soil averaged the highest afternoon temperature (40.7°C ± 5.3), followed by bare plastic mulch (36.2°C ± 2.1). The plastic mulch and soil that were covered by yam canopy averaged 33°C each (Fig. 2).

Once there was reduction in soil moisture for plots that were not mulched, the leaves were shed, and the soil temperatures increased markedly in the afternoons. Some plants with plastic mulch still retained green leaves at harvest. Mean soil moisture under the plastic mulch 1 week before harvest was 6.7% and was significantly different ($P < 0.01$) from that (2%) of unmulched soils.

There was no adverse effect of the plastic mulch on the tubers. Termites, mealybugs, and nematodes were present in negligible quantities in all plots; however, *Pratylenchus sefaensis*, root-lesion nematodes, were found only under the plastic mulch and could make a difference if the next crop is a host. Although yield differences were marginal, other than those for Nwapoko, the value of the labour saved and the increased yield was appreciable.

NATURAL ANTIFUNGAL COMPOUNDS FROM THE PEEL OF YAM TUBERS

S.K. OGUNDANA,[1] D.T. COXON,[2] AND C. DENNIS[2]

Two phenolic compounds were isolated from the peel of *Dioscorea rotundata* tubers by thin-layer chromatography. They acted as a fungicide against the bioassay organism *Cladosporium cladosporioides* and the pathogens causing storage rot of yams. The toxic compounds were identified with the aid of ultraviolet and infrared spectroscopy, nuclear magnetic resonance, and mass spectrometry: 2,5-dihydroxy-4-methoxy-9,10-dihydrophenanthrene and 7-hydroxy-2-4,6-trimethoxyphenanthrene. Both compounds were found to be absent in the yam flesh.

Resistance to fungal diseases has been reported to be provided by chemical substances present in plants, either before attack (Angel et al. 1930; Link and Walker 1933) or in response to infection by pathogens (Kue et al. 1956; Cruickshank 1963; Sakuma and Tomiyama 1967; Tomiyama et al. 1968; Barnes and Kue 1972; Lyon 1972; Alen and Kue 1974), but there is no record of isolation of natural antifungal compounds from yam tubers up to date.

As previous work (Ogundana et al. 1970) showed that the soft-rot pathogens of the yam tuber are wound parasites, this experiment was undertaken to investigate the biochemical basis of natural resistance of the yam peel to infection.

MATERIALS AND METHODS

Yam tubers were thoroughly washed with water and left to dry. The peel tissue was taken from a 1-mm-thick layer from the outer surface of the intact tubers, and flesh was taken from the innermost (parenchymatous) tissue. These extracts were separately prepared: 50 g of fresh weight of each were extracted with peroxide-free diethyl ether, 10 mL/g for 30 minutes, and filtered through a sintered funnel. The filtrate was collected and dried under reduced pressure at approximately 40°C. The filtrate residue was finally taken up in 500 mL of cyclohexane ethyl acetate for chromatography. Volumes (10 μL) of each solution were spotted onto thin-layer (TLC) plates in duplicates and developed in equilibrated tanks containing either methanol : chloroform (4 : 96 v/v); or cyclohexane : ethyl acetate (1 : 1 v/v); or hexane : ether (2 : 1 v/v). One set of the developed TLC plates was exposed to iodine vapour so that we could locate spots, and the duplicates were used for the bioassay tests.

The test organism used was *Cladosporium cladosporioides* (Garrod et al. 1978). The fungus was cultured on potato-dextrose agar (PDA) slopes at 25°C for 7 days. Spores were harvested in about 5 mL/slope of glass-distilled water (GDW) plus 1% Tween 80 and filtered twice through two layers of sterile muslin to remove agar and mycelium. The solution was then centrifuged for 10–15 minutes, and the supernatant solution decanted. Spores were washed in two changes of GDW and finally taken up in potato-dextrose broth (PDB); the concentration was adjusted to approximately 1.6×10^6 spores/mL.

The TLC bioassay test was similar to that of Homans and Fuchs (1970). Developed TLC plates were sprayed with the spore suspensions of *C. cladosporioides* in PDB. The plates were then incubated in cake boxes lined with moist filter paper for 4 days in darkness at 25°C, so that we could determine antifungal compounds. The bioassay test was repeated for the soft-rot pathogens of yam.

The percentage inhibition of germ-tube growth was estimated for *Aspergillus niger*, *Botryodiplodia theobromae*, *Fusarium moniliforme*, and *Penicillium sclerotigenum*, the soft-rot pathogens and the test fungus, *C. cladosporioides* incubated with and without the antifungal compounds under identical condi-

[1] Department of Microbiology, University of Ife, Ile-Ife, Nigeria.
[2] A.R.C. Food Research Institute, Norwich, UK.

tions. The lethal dose values (ED_{50}) were then obtained.

Approximately 2 kg of yam peel was soaked in two changes of 5 L distilled peroxide-free diethyl ether, each time at 13°C for 3 days, and decanted. The combined extracts were filtered through sintered funnel and evaporated to dryness. The extract was dissolved in the minimal amount of cyclohexane : ethyl acetate (1 : 1 v/v) and subjected to column chromatography on silica gel (1 g extract/100 g silica gel). Fifteen millilitre fractions were collected and evaporated. The fraction residues were separately taken up in the solvent and spotted onto TLC plates and developed in various solvents. The solvents included 4% methanol in chloroform (containing 2% ethanol), cyclohexane : ethyl acetate (various proportions), chloroform : ether (4 : 1 v/v), toluene : methanol : acetic acid (10 : 2 : 1), and various proportions of petroleum ether : diethyl ether : acetic acid. The fractions that gave best separations of antifungal compounds were combined and subjected to a second column chromatography with neat chloroform as the solvent and streaked across preparative 0.5-mm TLC plates in a narrow band 2 cm from the edge (about 30 mg streaked/plate) and developed with petroleum ether : diethyl ether : acetic acid (45 : 50 : 5) solvent, which gave best separation in earlier experiments. We detected the compounds by spraying the markers at the side of the streak with iodine solution. Antifungal compounds were then separately eluted from unsprayed bands of same R_F values as those of the markers with 40 mL of solvent and evaporated to dryness.

The ultraviolet spectrum was determined with a pye unicam S.P. 800 spectrophotometer. The infrared spectrum was obtained on a thin film between NaCl plates with a Perkin Elmer 297 spectrophotometer. Mass spectrometry and the 90-MHz proton magnetic resonance spectrum were also determined.

Results and Discussion

No antifungal compounds were detected in the yam flesh. The bioassay of the peel extracts showed three antifungal regions at R_F 0.30, 0.43, and 0.68 in methanol–chloroform solvent. Only the two R_F components with strong antifungal activity were examined in the present study.

High resolution mass spectrometry of the more-polar compound (R_F 0.43) showed a molecular ion of m/e 242.0908 indicating the formula $C_{15}H_{14}O_3$. The less-polar compound (R_F 0.68) gave a molecular ion at m/e 284.1052 corresponding to the formula $C_{17}H_{16}O_6$.

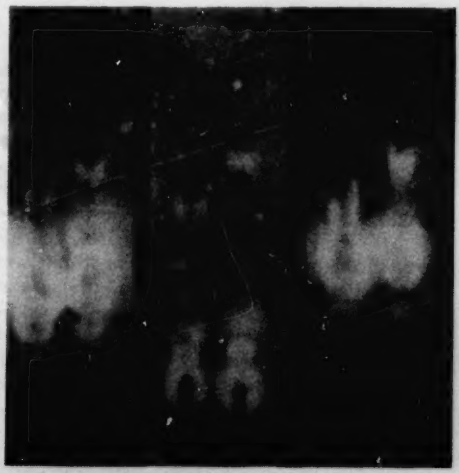
Table 1. Lethal-dose values (μg/mL) for two compounds against germ-tube growth.

	Compound	
	More polar	Less polar
B. theobromae	16	79
F. moniliforme	65	38
P. sclerotigenum	41	32
A. niger	42	14
B. cinera	44	100
C. cladosporioides	26	59

The TLC plates sprayed with spore suspensions of the test fungus and of the soft-rot pathogens of yam gave rise to germination inhibition zones. Both compounds affected germ-tube growth of all the fungi employed (Table 1).

We record here for the first time the presence of naturally occurring antifungal compounds in the peel of yam tubers. The UV spectrum of the more-polar compound ($C_{15}H_{14}O_3$) appeared virtually identical to that reported for hircinol (Urech et al. 1963), a phytoalexin of orchid. Both the UV and mass spectra of the less-polar compound ($C_{17}H_{16}O_6$) correspond closely with the spectra reported for batatasin 1 (Hashimoto et al. 1974).

The direct spraying of the thin-layer chro-



TLC plates incorporating yam-peel compound show growth inhibition of spore suspensions.

matograms with spore suspension is a technique that has been successfully used in detection of fungitoxic compounds against *A. niger*, *Ascochyta pisi*, *Botrytis cinera*, *Colletotrichum lindemuthiamum*, *Fusarium culmorum*, and *Penicillium expansum* (Homans and Fuchs 1970). Hircinol, similar to one of our compounds, has been shown in vitro to exhibit antimicrobial activity against a range of microorganisms. Urech et al. (1963) found that concentrations greater than 500 mg/mL were necessary to inhibit *A. niger* completely, even though our compound became lethal at 42 mg/mL (Table 1). Similarly, our less-polar compound demonstrated antimicrobial activity against the test fungi employed.

These antifungal compounds are of interest, as they occur in the peel of the yam tubers where they function as preformed inhibitors in disease resistance apart from the skin. The isolation and synthesis may ultimately be a breakthrough for the control of storage rot of yams. Further studies to determine whether the compounds also accumulate in response to infection in yam are in progress.

The financial support given by the Nuffield Foundation (UK) for this work and the grant by the International Foundation for Science (Sweden), as well as sponsorship at this symposium, to one of us (SKO) are gratefully acknowledged.

Optimal time for fertilization of *Dioscorea rotundata*

S.C.O. Nwinyi[1]

I compared the effects of applying fertilizer at 8, 9, 10, 11, and 12 weeks after planting (WAP) to determine the best time for fertilization of white yam (*Dioscorea rotundata* cv. Nwapoko). In 1981, the differences between treatments were not significant from each other or from the control (no fertilizer); but, in 1982, yields for all treatments were significantly higher than those for the control (ranging between $P < 0.05$ and $P < 0.001$) but not significantly different from one another.

Sobulo (1972b) reported that the last week of April or the first week of May was ideal for fertilization of yams planted in December–February in western Nigeria. Koli (1973) reported good response from split applications at 4 and 12 weeks after planting in northern Ghana. Onwueme (1978) recommended fertilization at 1 month after shoot emergence, whereas Obigbesan and Agboola (1978) recommended waiting until the yam vines are established. Enwezor and I (1980) suggested that the best time was 9–12 weeks after planting (WAP), which, according to Yayock et al. (1980), is similar to the practice in Nigeria, fertilizer being applied at about 8 WAP or as soon as the soil is sufficiently moist. Recognizing that the onset of rains and their distribution influence the time for planting and fertilization, I attempted to determine the most suitable time to fertilize rainfed white yam to boost yields in eastern Nigeria.

Materials and Methods

The study was carried out at Umudike in 1981 and at Umudike, Nsukka, and Igbariam in 1982. The two experimental sites at Umudike were at the National Root Crops Research Institute, 122 m above sea level. Although the sites had been cultivated earlier, there was no record of fertilization. The site at Nsukka was at the University of Nigeria faculty of agriculture farm, 447 m above sea level. The site was sandy and had not been cropped since 1976 when it was acquired by the university. The site at the Igbariam farm settlement, 34 m above sea level, was on ground that had been planted to palm but was bulldozed in 1979 and allowed to revert to bush (mainly *Imperata cylindrica*, *Eupatorium* spp., *Andropogon tectorum*, and mixed shrubs).

In each location, the field was cleared of existing vegetation, burned, plowed, and harrowed before being divided into 0.144-ha sections for the experiment. Ridges, 1 m high, were formed with a mould-board ridger, and 30 plots (8 m × 6 m), consisting of six 8-m-long ridges each, were planted with setts (average weight 0.25 kg) of *D. rotundata* cv. Nwapoko, 1 m × 1 m apart. The soils were analyzed, and, after sprouting, the yams were staked singly, two stakes from each of two adjacent ridges being tied together to ensure effective support. The plots were kept weed-free by hand.

Fertilizer (100 kg N, 40 kg P, 100 kg K) was placed in a 3–4 cm deep groove on both sides of the ridges, 15 cm from the crest. The different treatments were for time of application (8, 9, 10, 11, or 12 WAP and no fertilization as the control). The experimental design was a randomized complete block, with five replications. The yams were allowed to grow till complete senescence of the aerial parts and were harvested 30 WAP.

Results and Discussion

At the two sites in Umudike in 1981, the soils were not deficient (Table 1), and, thus, the control plots were able to support yields that did not differ significantly from those for fertilized plots. In 1982, however, the soils were nutrient poor, and yields from the control plots were

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

Table 1. Results of soil analyses at the experimental sites (0–23 cm deep).

Site (Planting date — day/ month/year)	pH	Organic carbon (%)	N (%)	P (ppm)	Carbon exchange capacity (meq/100 g)	Total exchangeable base (meq/100 g)			
						Ca	Mg	K	Na
Umudike									
(9/4/81)	5.80	1.95	0.157	3.25	6.08	2.672	2.345	0.172	0.029
(22/4/81)	5.50	1.50	0.224	4.02	2.21	0.695	0.740	0.203	0.029
(30/3/82)	4.95	1.54	0.138	0.00	5.60	0.075	2.56	0.584	0.131
Nsukka									
(14/4/82)	5.00	0.64	0.057	3.675	2.23	0.035	1.44	0.481	0.044
Igbariam									
(12/5/82)	5.10	0.49	0.044	0.00	3.54	0.065	2.48	0.584	0.070

Table 2. Fresh tuber yield (t/ha) of *D. rotundata*.[a]

	Planting date (day/month/year)				
	Umudike			Nsukka	Igbariam
	9/4/81	22/4/81	30/3/82	14/4/82	12/5/82
Control	18.33	12.97	13.92	13.68	14.78
Treatment (WAP)					
8	—	—	18.83*	22.05**	15.93NS
9	22.01NS	13.90NS	19.17*	21.63**	21.25***
10	22.77NS	15.56NS	18.50*	21.83**	21.03***
11	20.30NS	15.06NS	21.67**	24.02***	19.40**
12	20.28NS	16.27NS	22.25**	23.15***	18.43*

[a]Significance levels: NS = not significant; * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001.

significantly lower than those from fertilized plots. Although the yields generally increased with the length of time before fertilization, the differences between treatments were not significant except on the Igbariam plots. The trend for increasing benefit with increasing time before fertilization did not hold for the Igbariam plots, probably because the rains had stopped and the last two applications were preceded by about a month of dry weather. This finding confirms Sobulo's (1972b) observation that rainfall distribution affects the optimal time for fertilization.

The results suggest that fertilization of white yam is effective any time from 8 to 12 WAP. Hamid (1973) and Fayemi (1966) showed that fertilizer application is most effective when it corresponds to the critical time of increased nutrient requirement of the crops, and Jones (1973) observed that root growth of crops kept pace with downward wetting of the subsoil. Jones (1976) further reported that leaching efficiency varied with texture of the soil and that a low-leaching efficiency was related to slow wetting of the subsoil. These findings support the practice of applying fertilizer after the onset of rains, about 8 WAP, and support the observation (Sobulo 1972b) that annual rainfall distribution affects the best time for fertilizer application.

I wish to thank the Director, National Root Crops Research Institute, Umudike, for provision of facilities for this work, and for permission to publish it. I am particularly indebted to S.W. Agua and R.U. Onukwubiri for their assistance at various stages of this work.

EFFECTS OF STAKING ON TUBER YIELD OF THREE CULTIVARS OF TRIFOLIATE YAM

S.N. LYONGA AND J.T. AMBE[1]

At Ekona, South West Province, Cameroon, in 1979–81, three cultivars of trifoliate yam (Jakiri, Muyuka, and local) were compared for their tuber yields on ridges of staked and unstaked plots. Blocking was done according to treatments and oriented in an east–west direction so that staked plants would not shade unstaked ones. The tuber yields differed significantly among cultivars (main plots). Although staked and unstaked treatments did not differ markedly in yield, the staked plots were easier and cheaper to maintain, had a lower prevalence of fungal disease, and produced more male and female flowers than did the unstaked plots.

Traditionally, farmers in Cameroon do not stake sweet yams (*Dioscorea dumetorum*). This is particularly true in the savanna areas of the northern parts of the country where stakes are scarce. The vines either cluster to form a natural stake or climb on cereal stakes left in the field after harvest. The tuberization of the sweet yam has been negatively geotropic. Hence, there is constant mulching with soil so that the tubers do not become exposed and hardened. To mulch in an unstaked field of sweet yam is difficult and expensive, and at least some of the vines that are creeping will be cut, with reductions in yield.

In the forest zone of the country, yams are grown in mounds, whereas ridging is the practice in the savanna and also at experimental stations. In both zones, sometimes holes are dug, especially for *D. alata* and *D. rotundata*, but this approach is very expensive.

Various authors have reported beneficial effects of staking yams, with substantial yield increases being associated with increasing heights of staking. Waitt (1963) reported that the response of yams was species dependent, with *D. dumetorum* and some others not needing stakes. In Guadeloupe, Rouanet (1967) showed no differences between staked and unstaked *D. alata*. Doku (1967) reported that the effects of staking differ according to cultivar and location but that higher yields are realized from staked plots. We investigated the effects of staking on the fresh tuber yields of three cultivars of *D. dumetorum* at two locations in Cameroon.

[1] Cameroon National Root Crop Improvement Programme (CNRCIP), Njombe, Cameroon.

MATERIALS AND METHODS

A series of trials from 1979 to 1981 was set up at Mile 17 and Yoke. Staked and unstaked plots were compared for three cultivars — Jakiri, Muyuka, and local. The plots were plowed and harrowed. The setts, 300–400 g, were planted on ridges at a spacing of 1 m × 1 m, and blocking was done from east to west so that staked plants would not shade unstaked plots. A split-plot, randomized design was used, with cultivars being main plots (with four replications) and staking as subplots. Subplots were 4 m × 10 m, with the experimental plots being 2 m × 8 m (16 stands). The data collected were stand count 90 days after planting and at harvest; fresh tuber clusters at harvest; fresh weight of tubers; and disease incidence.

Planting was done in March, and tubers were harvested in November. Statistical analysis was carried out, and the data on yields were extrapolated to a per-hectacre basis.

RESULTS

In all the years, Jakiri significantly ($P < 0.05$) outyielded the Muyuka and local cultivars (Table 1). In 1979, at Mile 17, staked plots outyielded unstaked plots in all three cultivars, but only Jakiri showed a significant yield difference in staked (34 t/ha) over unstaked (26 t/ha) treatments.

Leaf-spot (fungal) diseases were prevalent in all the cultivars, but plant counts 90 days after

Table 1. Fresh yield of three cultivars of *D. dumetorum* (kg/m²).[a]

Treatment	Mile 17[b]			Yoke[c]	
	1979	1980	1981	1980	1981
Jakiri					
Staked	3.4*	2.6**	2.5	2.0*	2.0*
Unstaked	2.6	2.4	2.7**	1.5	1.6
Muyuka					
Staked	1.5**	1.8**	1.5**	1.1	1.4**
Unstaked	1.3	1.6	1.3	1.0	1.2
Local					
Staked	2.4**	1.8	2.1	1.4**	1.2**
Unstaked	2.2	1.8	2.5**	1.2	1.0

[a]Significance levels: * = 5%; ** = 1%.
[b]Coefficient of variation = 19%; standard deviation = 0.5 kg.
[c]Coefficient of variation = 20%; standard deviation = 0.3 kg.

planting and at harvest showed 93% survival. The 7% difference in plant population on experimental plots was not serious enough to cause border effect, as yields/plant were not significantly different from yields/m².

Dioscorea dumetorum produces clusters rather than individual tubers. An average 1.5 clusters/plant were recorded at harvest.

Discussion and Conclusion

Compared with Muyuka and local, Jakiri cultivar was consistently the highest yielder, but it has a distinct disadvantage in that its tuber hardens quickly when exposed to air at ambient temperature. The tuber of Muyuka cultivar takes a long time to harden. Efforts should be intensified to delay Jakiri's hardening. Although the yields from staked plots were not significantly larger than those from unstaked plots, the staked treatments of all three cultivars produced more male and female flowers than did unstaked treatments, and this characteristic could be exploited in breeding programs. Other agronomic advantages were derived from the staked plots. Operations such as weeding, mulching, and harvesting were facilitated. For commercial cultivation of this yam, where additional inputs like inorganic fertilizers will be used, staking is advisable so that during fertilizer application and mulching with soil the yam vines will not be destroyed. Fungal diseases were more prominent on the unstaked plots, and the creeping vines on the ground were particularly vulnerable to pests such as crickets and beetles.

EFFECT OF TIME OF STAKING ON THE DEVELOPMENT OF ANTHRACNOSE DISEASE OF WATER YAM

A.O. NWANKITI AND I.U. AHIARA[1]

We studied the effects of staking at four different periods on the development of anthracnose disease of water yam (*Dioscorea alata*) caused by *Colletotrichum gloeosporioides*. Plots staked 63 and 84 days after planting and unstaked plots showed severe anthracnose infections. Disease decreased with earlier staking (21 and 42 days after planting). Yield reductions increased with delay in staking. The peak of leaf production for all the treatments was between 4.5 and 5 months after planting. Serious defoliation of the vines occurred in susceptible cultivars 5 months after planting when staking was delayed.

The importance of supporting yam vines with stakes has been delineated elsewhere (Onwueme 1978), the principal advantage appearing to be increased insolation on the leaves. Another advantage seems to be that staking keeps vines and leaves away from the soil and protects the plant from an anthracnose-causing organism, *Colletotrichum gloeosporioides*, which has been found to survive in soil from one season to another (Nwankiti 1982). This possibility is supported by our studies on the effect of staking on anthracnose disease.

MATERIALS AND METHODS

Two *Dioscorea alata* cultivars were grown in 1981 and 1982 on different sites at the experimental farm of the National Root Crops Research Institute (NRCRI). The soil was a well-drained sandy loam and was previously cropped with anthracnose-susceptible cultivars of water yam. In April of each year, two cultivars — one resistant and the other susceptible (growing period 7–8 months) — were assigned at random to the whole plots within each of the four replicates of the experiment. The whole-plot design was a randomized complete block. (The plots received appropriate and standard cultural treatments for yams.) No fertilizers were applied. Average temperatures, relative humidity, and rainfall were obtained from the meteorological centre at Umudike.

Stakes about 3 m high were used for four treatments — staking at 21, 42, 63, and 84 days after planting. An unstaked treatment served as the control. The vines were carefully separated before being staked at 63 and 84 days after planting because of the risk of breaking the succulent part of the vine.

Anthracnose of water yam causes defoliation (Nwankiti 1982); therefore, leaf production was assessed: four stands in every plot were labeled for leaf-production measurement. For the first 100 days after planting, leaves were counted in situ. Mean number (from four plants) of leaves per stand for each measurement was determined. After 100 days, leaves were so many that subsequent measurements were carried out by destructive sampling. At 115 and 130 days after planting, two of the four labeled stands from each plot were uprooted and the whole leaves counted.

The disease was scored 5 months after planting according to the percentage of foliage exhibiting signs of infection: 1, 0–10%; 2, 11–30%; 3, 31–50%; 4, 51–75%; and 5, 76–100%. Tubers were harvested and weighed in November of each year after all the yams were mature.

RESULTS

During the crop-growing season, the weather was exceptionally good in both 1981 and 1982. Fortnightly total rainfall and average temperatures and relative humidity were taken between April (when the yams were planted) and August

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

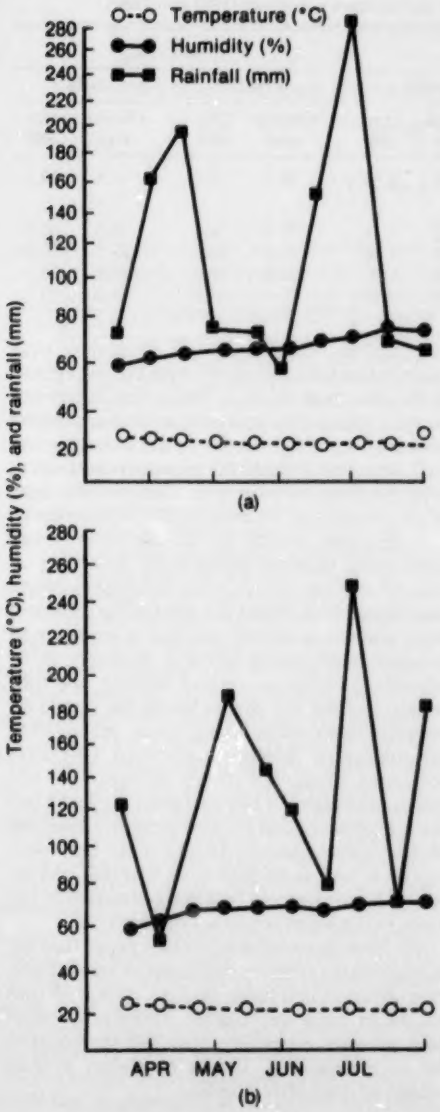


Fig. 1. *Fortnightly mean temperature, humidity, and rainfall in Umudike, (a) 1981 and (b) 1982.*

(when leaf-production measurements were terminated). The highest rainfall — 272 mm and 269 mm for 1981 and 1982 respectively — was in the last week of July. The highest mean relative humidity was also in the last week of July (84%) for 1981 and the last week of August for 1982 (85%). Average temperatures ranged from 25°C in August for the 2 years to 28°C in April 1981 and 27.5°C in April 1982 (Fig. 1).

At the fifth sample harvest of both years, the highest number of leaves was recorded, and generally there was a sharp decrease thereafter (Fig. 2). More leaves were produced by the resistant cultivar than by the susceptible one. Generally, the plants that were staked at 21 and 42 days retained more leaves than those staked later.

Leaves were lost heavily between July and August in plots staked later than 42 days after planting. Some leaves were also lost when vines

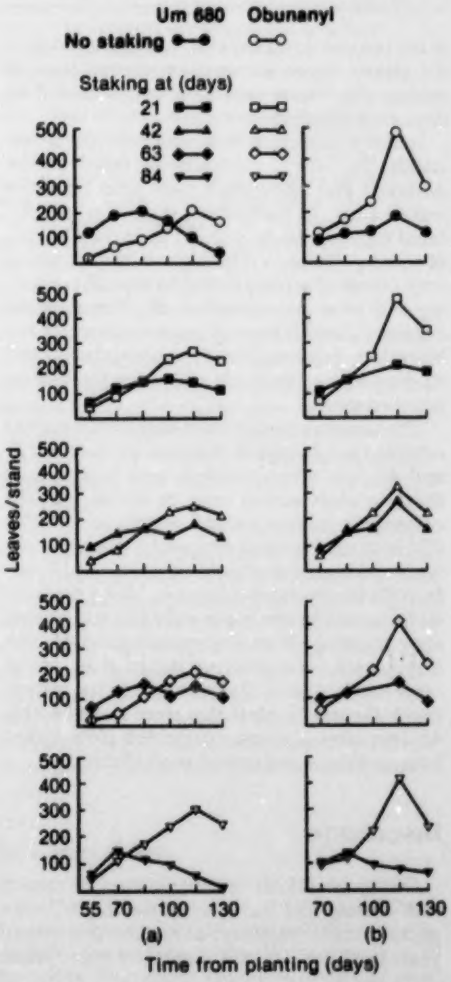


Fig. 2. *Effect of periodic staking on amount of leaves produced by two cultivars of* D. alata, *1981 and 1982.*

Table 1. Severity scores for anthracnose disease and yields of water yam (1981 and 1982).

	Severity score				Yield (t/ha)			
	1981		1982		1981		1982	
	Obuna-enyi	Um 680	Obuna-enyi	Um 680	Obuna-enyi	Um 680	Obuna-enyi	Um 680
Unstaked	3.42	1.12	3.78	1.34	20.2	22.1	14.9	18.5
Staked (days after planting)								
21	2.32	1.10	2.12	1.18	31.4	36.1	26.6	40.3
42	2.29	1.11	2.84	1.38	26.7	30.8	23.8	37.7
63	2.44	1.18	3.09	1.30	30.2	31.6	21.4	38.0
84	3.73	1.24	4.12	1.40	13.0	27.5	12.2	27.2

in the last two treatments were being raised onto the stakes. Some stands even showed signs of wilting after being raised on stakes 63 and 84 days after planting.

Initially, infection was observed on a few stands, the rate of spread being faster on the unstaked and late-staked yams than on those staked early. In both years, disease scores differed significantly ($P < 0.05$) according to time of staking (Table 1). The highest disease scores were obtained in plots staked 84 days after planting and plots not staked at all. The resistant cultivar (Um680) showed some measure of stability during disease attack: stands staked 21 and 42 days were reasonably free from the disease manifestations.

The severity of infection in each treatment was reflected in tuber yield. Yields in plots staked 21 and 42 days after planting were higher than those in plots staked later or not at all. The susceptible cultivar yielded as high as 31.4 t/ha (Table 1) when staked very early, whereas a delay in staking reduced yields to as little as 13 t/ha. In 1982, the resistant cultivar yielded a dramatic 40.3 t/ha and 38 t/ha when staked 21 and 63 days after planting. Plots that were staked 84 days from planting and plots not staked at all, on the other hand, yielded 27 t/ha and 18.5 t/ha, respectively. Generally, plots that were staked within 42 days after planting outyielded plots staked later and those not staked at all (Table 1).

Discussion

Onwueme (1978) cited reduction in mutual leaf shading and increase in insolation (hence photosynthetic capacity) as reasons that staked yams yield more than do unstaked ones. Water yam, unlike other species of *Dioscorea*, produces leaves simultaneously with the emergence of the vine from the soil. These first leaves can become infected by anthracnose disease (caused primarily by *C. gloeosporioides* infesting the soil), which constitutes the greatest constraint in the production of water yam. Hence, early signs of infection occurred even on plots staked early.

In this trial, results for disease severity and tuber yield differed significantly according to time of staking. These wide differences might also reflect the fact that the vines of the unstaked plots and those staked late had a tendency to produce many leaves initially, probably as an attempt to overcome mutual shading, and they tended to hang low and be bushy, the humid air beneath them encouraging spore germination and subsequent infection and spread. This latter tendency produced heavy infection of the leaves, especially in July and early August when the temperature and relative humidity favoured disease development. In the plots that were staked as late as 84 days from planting, the infected leaves were so tenuously attached to the vines that a slight touch shook them off.

We have demonstrated in this paper that delaying staking of vines can result in heavy infections from anthracnose disease, which in turn results in yield depression. Therefore, water-yam cultivars, especially those that are susceptible to anthracnose, should be staked at least within 42 days after planting.

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THERMODYNAMICS APPLIED TO THE STORAGE OF YAM TUBERS

GODSON O. OSUJI[1]

The prolonged storage of yam tubers requires the design and construction of an adequate environment. The nature of such an environment can be mathematically conceived from the biological properties of the tubers; the final developmental step is the experimental testing of the environment for its efficiency in the storage of the tubers. The influence of thermodynamic factors on the yam tuber provides the necessary parameters for the mathematical formulation of the adequate storage environment. The lack of progress in the design and development of an appropriate environment is, I believe, attributable to the absence of mathematical calculations to guide the research. Yam tubers can theoretically be stored under either isothermal or adiabatic conditions. Mathematically, one can predict that, under isothermal conditions, the weight of the tuber would remain constant, with the internal energy of the tuber being utilized for increasing the randomness of the molecular structure of the tuber, whereas, under adiabatic conditions, the weight of the tuber would change inversely with a change in temperature — i.e., a slow rise in temperature would produce a gradual decrease in weight. The isothermal conditions are unsuitable for the storage of yam tubers because the increasing molecular disorder at a constant tuber weight would shorten the life of the tuber. An adiabatic environment, on the other hand, should be suitable because it allows the weight of the tuber to decrease slowly, ensuring that the internal energy of the tuber is utilized for counteracting the internal forces of molecular repulsion resulting from the decreasing weight.

The yam tuber experiences a high degree of postharvest deterioration caused by physical damage, microbial infection, endogenous physiological reactions, and fluctuating storage temperatures (Booth 1974; Osuji and Umezurike 1983). Measures recommended for the control of these losses include refrigeration (Booth 1974); curing (Gonzalez and Collazo de Rivera 1972); chemical treatment (Passam et al. 1976); high-temperature treatment (Martin 1955); and irradiation (Rivera et al. 1974). None of these measures has been widely adopted. The technology must be simple enough for the farmers who are currently using traditional methods (Wilson 1980). Attempts in laboratories to develop cold-storage technology for the tubers have been abandoned because the tubers are susceptible to low-temperature damage. To develop a simple technology, one needs to understand the biochemistry of the tubers in relation to their environment because they continually interact with the environment. The relationship between a system (the yam tuber) and its environment (the storage atmosphere) is best studied through the application of thermodynamics.

[1] Department of Applied Biochemistry, Anambra State University of Technology, Enugu, Nigeria.

The aim of this study is to formulate mathematically, based on the biochemistry of the tubers, the thermodynamic relationships that are optimal between the yam tuber and its storage environment. Such a mathematical formulation would guide the technological research, design, development, and construction of the storage environment.

The storage of fresh yam tubers is justifiable not only from the economic point of view but also from the biochemical point of view. Biochemical studies have shown that the biological half-life of the tuber is 1 year (Osuji 1981). This means that, under optimal storage conditions, the tuber will remain healthy for a minimum of 1 year, which is long enough to permit the next crop of tubers to be harvested. If the half-life were short as is the case with cassava roots, any effort to store them fresh would be unjustifiable.

BIOCHEMISTRY

Biochemical interactions occurring between the yam tuber and the external environment are the basis for a study of the thermodynamics of the tuber. The major reactions occurring in a

healthy yam tuber during storage are respiration and desiccation, sprouting, and protein catabolism. These reactions, which culminate in the deterioration of the tubers, have been intensively studied (Coursey 1967a; Olorunda and Macklon 1976; Osuji 1981; Ikediobi and Oti in press). Respiration and desiccation cause the tubers to lose weight, and the weight losses have been converted into thermodynamic energy losses (Osuji and Umezurike 1983). They are a linear function of the storage age of the tubers. The optimal storage environment would minimize (but not eliminate) the weight losses.

Recently, my colleagues and I have demonstrated that the proteins of yam tuber are undergoing proteolytic degradation. We are having several proteolytic enzymes of the tuber purified for detailed studies, with the aim of designing adequate methods for their control in vivo. If the small amount of protein that tubers contain is lost through proteolysis in vivo, the tubers will rapidly deteriorate. To prolong storage of the tubers, one must inactivate the proteolytic enzymes, but the weight losses of the tuber thermodynamically activate the enzymes. If weight losses are minimized, then the proteolytic enzymes will possess minimal energies.

Sprouting of the yam tuber is also a preprogramed biological process, which occurs at about 12 weeks after the harvest of the tubers (Ikediobi and Oti in press). During sprouting, all the enzymes of carbohydrate metabolism experience increased activities so that the tubers suffer the highest weight losses during this time. Thus, slowing weight losses will control sprouting and thereby prolong the shelf-life of the tubers.

These biochemical studies point to weight losses as the key to storage of the tubers. The thermodynamic formulation of the optimal storage environment, therefore, focuses on factors that affect the weight of the tuber.

The functions of state in the first law of thermodynamics (U = internal energy; P = atmospheric pressure; T = atmospheric temperature; H = enthalpy; and V = the volume of the system) can be applied to the yam tuber, with the only modifications being that H is the enthalpy of the respiration of the tuber and the weight of the tuber is a more practical measurement than volume.

The internal energy, enthalpy, and atmospheric temperature, which control the heat capacities of thermodynamic systems by influencing their volumes, control the heat contents of yam tubers by influencing their weights. Heat capacity of yam tubers at constant weight (C_w) is $(dU/dT)_w$ and, at constant pressure (C_p), is $(dH/dT)_p$. The heat capacity at constant pressure is larger than that at constant weight because, at constant atmospheric pressure and decreasing tuber weight, the heat produced is used both for causing an increase in the tuber's temperature and for effecting the decrease in the tuber's weight, whereas, at constant tuber weight, the heat produced is used only for causing an increase in the tuber's temperature. The heat utilized for effecting the decrease in the weight of the tuber is $C_p - C_w$ or $[P + (dU/dW)_T] (dW/dT)_p$, which is a statement of the first law of thermodynamics (Moore 1974). The respiratory energy/g of tuber is $(dU/dW)_T$, which is the internal pressure of the tuber. It is the force that propels the weight-decreasing reaction.

The term $P(dW/dT)_p$ represents the contribution to the heat capacity, Cp, caused by the change in weight of the tuber against the atmospheric pressure. As the yam tuber is a solid and does not increase in weight during storage, atmospheric pressure has no significant contribution to the heat content of the tuber. Thus, this term can be eliminated from the calculation of $C_p - C_w$.

The energy required for the decrease in weight against the forces of the internal pressure of the tuber is $(dU/dW)_T (dW/dT)_p$. It represents the increase in thermodynamic energy with decreasing tuber weight. For the yam tuber, the amount is very large because the decreases in weight of the tuber are assisted not by the external atmospheric pressure but by the deleterious biochemical reactions of the tuber. Internal energy must, therefore, be generated to overcome the internal repulsive forces of the molecules of the tuber during the weight-decreasing process. Thus, $C_p - C_w$ is equal to $(dU/dW)_T (dW/dT)_p$. The intermolecular repulsion is overcome by the biochemical degradation of the molecules rather than by the application of an external force to compress the molecules.

Application

The carbohydrate stored in the tuber is the major source of internal energy. Its fate depends on the work it does during tuber storage. The internal pressure of the tuber is also important in considerations of the work done by the stored carbohydrate. The internal pressure of the tuber is positive, very large, and increasing as the tuber decreases in weight.

In critical isothermal storage, the internal en-

ergy is not used for decreasing the tuber's weight but for increasing the internal randomness of the tuber, causing a rapid loss of molecular orderliness and leading to a rapid deterioration of the entire tuber. This conclusion derives from the first law of thermodynamics; enthalpy changes, measured in the second law of thermodynamics, lead to a similar conclusion. Thus, storage of yam tubers under isothermal conditions is not recommended, and my focus is on the potential for adiabatic storage.

Mathematical application of the first law of thermodynamics to the system clearly shows the weight of the tuber is related to its temperature and that, under adiabatic storage, the tuber's weight decreases as its temperature increases. The practical importance of this relationship is that, if the storage temperature is allowed to rise slowly, the weight of the tuber will correspondingly decrease slowly and this relation will enable the tuber to be stored for prolonged periods. Under this condition, the heat capacity of the tuber is utilized for effecting the decrease in weight rather than for increasing the randomness of the molecules of the tuber.

A consideration of the free-energy change, ΔG, and the entropy changes, ΔS, is important in the formulation of the environment for the storage of the tubers. The reason is that the tuber respires and, therefore, liberates energy, the accompanying decrease in the weight being an expression of the entropy changes inside the tuber. The energy change can be derived from the work done by the yam tuber as it loses weight. The intensive factor is the internal pressure, and the extensive factor is the loss in weight. The work done is the product of the two factors (Moore 1974). A gram of starch liberates 3.80 kcal of energy on complete oxidation. So, 3.80 kcal of work is done by the yam tuber when it loses a gram of weight. Booth (1974) observed that sound yam tubers lose a minimum of 30% of their weight during a storage of about 6 months. For a 100-g tuber, this loss amounts to 114.0 kcal of work. The work is positive; therefore, the weight-decreasing process is not a spontaneous thermodynamic reaction: the decrease in weight requires energy input to overcome the internal repulsion of the molecules of the tuber.

If — as is the case in adiabatic storage — the energy liberated from respiration is not lost to the atmosphere as heat but is completely absorbed by the molecules of the tuber, then the change in enthalpy, ΔH, equals 0, and the second law of thermodynamics reduces to $\Delta G = -T\Delta S$. $T\Delta S$ is the entropic work done by the yam tuber as the tuber loses weight during storage. The entropy change, ΔS, associated with the weight-decreasing process is, thus, $T\Delta S = -3.80$ kcal. Stored at room temperature (about 20°C), the yam tuber's entropy change would be $\Delta S = -12.66$ cal/g tuber. A negative change in entropy means that there is a high degree of orderliness in the yam tuber, despite the progressive decrease in tuber weight. The explanation for this is that the high entropic work associated with the decrease in tuber weight is not directed against all the molecules of the tuber but is directed selectively against those molecules that possess the repulsive intermolecular forces: mainly the starch molecules but also a few proteins and lipids. When the forces of repulsion are eliminated from the molecules, they increase in entropy and undergo enzymic degradation. The undegraded molecules then experience increased orderliness with increasing time in storage. In other words, theoretically, the entropy of the tuber decreases with increasing time in storage under adiabatic conditions. This deduction strongly favours adiabatic conditions for the prolonged storage of the tuber.

The selective degradation of the molecules of the tuber that possess repulsive forces is in agreement with experimental observations because, so far, only a few proteins of the tuber, namely the γ-glutamyl transpeptidase and polyphenol oxidase, have been observed to decrease in activity during tuber storage, whereas all the enzymes for carbohydrate metabolism increase activity during tuber storage. Therefore, the predicted thermodynamic influence of the adiabatic storage environment on the yam tuber has some experimentally demonstrable validity.

So far, the source of the energy for effecting the decrease in weight has been the internal energy, that is, the free-energy change of respiration.

This implies that, as the stored starch is burned, the tuber naturally loses weight. If some of the energy for propelling the weight decrease were supplied from an external source, then the internal energy of the tuber would be conserved. Under such a condition, the starch reserve would last longer and the rate of the weight decrease would be slower. The entropic work that propels the weight decrease is temperature dependent. If the temperature rises, the free-energy change would rise and the entropy change of the tuber would decrease. Thus, if the temperature of the storage environment were raised slowly, some of the energy for effecting the decrease in the weight of the tuber would be supplied externally and not from the respiratory energy of the stored starch. The heat transferred

to the tuber is nonadiabatic, whereas the respiratory energy is adiabatic. The ideal condition is to make the adiabatic energy equal to the nonadiabatic energy so that all the energy for the weight decrease is derived from the nonadiabatic work. In practice, the nonadiabatic work should be so selected that the temperature of the tuber is well below the optimum for physiological reactions.

The imposition of nonadiabatic work on the tuber is what earlier workers have called curing. But, in curing, the applied external temperature is high, with the result that the nonadiabatic work exceeds the adiabatic work. The consequence is that the tuber reacts against the excessive heat by increasing the thickness of its periderm instead of utilizing it to increase its total free energy.

The biological properties of the periderm of the yam tuber are important. In its functions, the periderm serves as an adiabatic wall by separating the yam tissues from the external surroundings and preventing the tuber from losing the adiabatic energy to the surroundings. It also functions as a diathermic wall by permitting the transfer of external energy into the tuber. These functions are in agreement with the experimental observations of Passam et al. (1976) that the tuber suffers increased losses in weight when the periderm is ruptured by bruises and wounds. Any rupture in the periderm creates an opening in the adiabatic wall through which the internal energy oozes from the tuber and through which external energy cannot be transferred to the tuber. The periderm is, therefore, the thermodynamic wall for maximizing the energy of the tuber. This explains why the tuber suffers rapid losses in weight when its adiabatic–diathermic wall is damaged. From this, it follows that the rise in temperature of rooms where yam tubers are stored is caused by the tubers with injuries.

Yam tubers sustain a variety of injuries during handling at harvest, transport, and storage. That the periderm is vital to the tuber is demonstrated by the rapid repair mechanism that is triggered whenever the periderm is damaged (Passam et al. 1976).

Recommended Storage Environment

The temperature and weight of the tuber are the important thermodynamic functions of state of the tuber. For proper storage, the tuber's temperature should be made to rise slowly throughout storage so that the tuber loses weight slowly. The temperature should neither be held constant nor be made to decrease, as such changes would cause adverse thermodynamic increases in the entropy of the tuber, and, at temperatures below 15°C, there would be additional damage to the tuber's membranes.

To ensure that the thermodynamic factors achieve their maximum expected effect, other nonthermodynamic factors need to be controlled — primarily damage by pests and pathogens and the initiation of sprouting.

A good number of pesticides have been demonstrated to be effective in control of the common pests (Onyenobi and Wright 1983), and chemical suppression of sprouting is under vigorous study.

One can also reduce the metabolic activity of the tuber by use of gamma irradiation, which appears to be the most important complement to thermodynamic factors. It deactivates the proteins and nucleic acids of the tuber so that the problem of entropy increase is minimized.

The prolonged storage of yam tuber will, therefore, be achieved by an integrated program in which the thermodynamic properties of the tuber are the central determinants. To ensure that the tuber's weight is decreasing and temperature increasing, one must store the tubers in an enclosed environment. The rate of respiration determines what temperature is most suitable for the environment. The engineering design of the environment, therefore, must allow one to regulate the temperature and the air flow into and from the environment. The shelves on which the tubers are to be stored should be designed to prevent physical injury to the tubers. An enclosed environment also permits effective chemical treatments. The storage area should house large quantities of tubers so that it is economically feasible, perhaps cooperatively owned and used by local yam growers.

ROOT-KNOT SUSCEPTIBILITY OF CROPS GROWN WITH YAM IN NIGERIA

U.G. ATU[1] AND R.O. OGBUJI[2]

Ten crops traditionally grown with yam in southern Nigeria were tested for resistance to *Meloidogyne incognita* race 2, in 1979–80. Results, based on gall indices and recovery of the larvae from soil and roots, showed that *Corchorus olitorus*, *Sphenostylis stenocarpa*, *Hibiscus esculentus*, and *Cucurbita pepo* were highly susceptible; *Amaranthus* sp., *Citrullus* sp., *Zea mays*, and *Manihot esculenta*, moderately susceptible; *Telfairia occidentalis*, resistant; and *Mucuna pruriens*, highly resistant. Planted on yam mounds, these crops could play an important role in altering the populations of root-knot nematodes.

Bridge (1978) noted that planting yam with crops susceptible to root-knot nematodes (*Meloidogyne incognita*) would increase the nematode population and the severity of damage to tubers. In fields where root-knot nematodes are problems, one should select resistant intercrops to control the pest (Wallace 1971; Seinhorst 1972; Ferris 1978; Ahuja and Arora 1980). This paper reports on the host status of crops commonly intercropped with yam in southern Nigeria.

MATERIALS AND METHODS

The study was undertaken at the National Root Crops Research Institute (NRCRI), Umudike, Nigeria, in 1979 and was repeated in 1980. The intercrops were obtained locally and are the 10 most commonly used in southern Nigeria. They were *Amaranthus* sp., *Manihot esculenta* cv. TMS 30211, *Corchorus olitorus* cv. Yaya, *Mucuna pruriens*, *Citrullus* sp., *Cucurbita pepo*, *Sphenostylis stenocarpa*, *Telfairia occidentalis*, *Zea mays*, and *Hibiscus esculentus*.

Three seeds or cuttings of each intercrop were planted in 10-L plastic buckets containing sterilized sandy loam; 5000 root-knot nematode eggs were added. Each treatment was replicated five times, the experiment being a randomized block design.

Five weeks after planting, 400-mL samples of soil were collected from the buckets for root-knot nematode bioassay; 2-week-old tomatoes, grown on steam-sterilized soil, were planted in the soil samples for comparison. Ninety days after planting, the intercrops were carefully lifted, washed, and root galls rated according to Sasser and Taylor (1978) on a scale of 0–5 (0 = 0, 1 = 1–2, 2 = 3–10, 3 = 11–30, 4 = 31–100, and 5 = > 100 galls). Larvae/2 g of roots were extracted by the jar-incubation method (Ayoub 1977). Larvae/200 mL of soil were also extracted with a modified Baermann funnel technique (tray method). The nematodes were counted under dissecting microscope.

RESULTS AND DISCUSSION

The intercrops differed in their status as hosts to *M. incognita* (Table 1). The root-gall index ratings on the tomato plants for the 2 years (1979–80) indicated that nematode reproduction was high on jute (*Corchorus olitorus*), okra, yam bean, and pumpkin. The only soil sample in which no appreciable galls occurred on the tomato plant was that from *Mucuna pruriens*.

In 1980, gall indices for melon, maize, and *Amaranthus* sp. were not significantly different from those of *Corchorus*, okra, pumpkin, and yam bean. In both years, the root-gall indices were lowest for *Mucuna pruriens*. No galling was observed on the roots of this crop in 1980 but nodulation was profuse; many blackish lesions were observed on the root system (Viglierchio 1978).

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

[2] University of Nigeria, Nsukka, Nigeria.

Table 1. Root-gall indices in roots of inoculated intercrops.

Intercrop	Root-gall indices[a]	
	1979	1980
Amaranthus sp.	2.0b	2.6ab
Cassava	2.4b	2.0b
Corchorus sp.	5.0a	5.0a
Maize	2.4b	2.8ab
Melon	2.0b	2.8ab
Mucuna sp.	1.0c	0.0c
Okra	5.0a	5.0a
Pumpkin	5.0a	5.0a
Telfairia	1.8b	2.0b
Yam bean	5.0a	5.0a

[a]Each figure is the mean of five replicates. Means followed by the same letter do not differ significantly (P = 0.05) according to Duncan's multiple-range test.

Numbers of *M. incognita* larvae extracted from plant roots and surrounding soils reflected the amount of galling on the plants. Intercrops with high gall indices supported high nematode larval populations. The only exception was maize, which had low gall indices but high larval populations (316 and 358 in 1979 and 1980, respectively). This type of response had been reported in other gramineous plants (Martin 1956a). The fewest larvae were recovered from soil samples of cowitch and telfairia, significantly lower numbers than from other intercrops.

From this study, yam beans, okra, pumpkin, and *Corchorus* sp. could be classed as highly susceptible; maize, melon, *Amaranthus* sp., and cassava moderately susceptible; telfairia resistant; and *Mucuna* sp. highly resistant. Some of these intercrops are planted on yam mounds. If highly susceptible intercrops like okra and pumpkin are placed close to yam plants, attack on yams by root-knot nematodes will be more severe (Atu 1982).

Several crops are planted on yam mounds by smallholders in Nigeria. Planting of the resistant intercrops like cowitch and telfairia would prevent rapid population buildup around yam plants.

EFFECTS OF COVER PLANTS ON ROOT-KNOT NEMATODE POPULATION

U.G. ATU[1] AND R.O. OGBUJI[2]

In areas where yam is usually the first crop in a rotation after fallow, it makes sense to manage the fallow lands so that the soil is not only fertile enough to support yam but also free from the pests affecting the crop. Recognizing this, we evaluated 14 cover plants commonly found or grown in fallow in southern Nigeria for their resistance to root-knot nematode, *Meloidogyne incognita*. In glasshouse and field experiments, *Crotolaria retusa*, *Arachis hypogaea*, *Stylosanthes gracilis*, *Tagetes patula*, and *T. erecta* were highly resistant; *Centrosema* sp., *Panicum maximum*, *Eupatorium odoratum*, and *Aspilia latifolia* were resistant; and *Calopogonium* sp., *Pueraria* sp., *Cajanus cajan*, *Vigna unguiculata*, and *Cynodon dactylon* were susceptible.

In Nigeria in the past, lands were cultivated for one season and then left fallow for 4–5 years during which they returned to rain-forest conditions, dominated in the southeast by *Acio barteri* and *Anthonotha macrophylla* and in the west by *Gliricidia sepium*. But with growth in population and consequent increase in the demand for farmlands, the fallow period has been reduced to about 1–4 years (Dalrymple 1971), and the climate climax vegetation has been replaced by what is now known as derived guinea savanna bush, mainly herbs or shrubs and perennial grasses such as *Eupatorium odoratum*, *Aspilia* spp., *Cynodon* spp., *Panicum maximum*, and *Calopogonium* sp. There are other introduced cover plants like *Stylosanthes gracilis* (stylo), *Pueraria* sp., *Crotolaria* spp., and *Centrosema* sp. At times, farmers plant legumes in the fallow to increase soil nitrogen. *Cajanus cajan*, *Arachis hypogaea*, *Mucuna* sp., *Vigna unguiculata*, and *Tagetes* spp. (Yousif 1979; Atu 1982) are some of the species used.

In areas where yam is the first crop in a rotation after fallow, farmers should ensure that the plants dominating the fallow are not good hosts for root-knot nematode (*Meloidogyne* spp.) (Edwards 1956; Peacock 1957; Bridge 1972; Nishizawa 1973; Adesiyan and Odihirin 1978; Ferris 1978; Atu 1982). The work reported here evaluates cover plants found or grown in southern Nigeria fallow for resistance to root-knot nematode, *M. incognita* race 2.

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.
[2] University of Nigeria, Nsukka, Nigeria.

MATERIALS AND METHODS

The experiment was conducted between 1978 and 1980 in a glasshouse and in the field at the National Root Crops Research Institute. The cover plants tested were Siam weed (*E. odoratum*), *Aspilia latifolia*, African marigold (*Tegetes erecta*), French marigold (*T. patula*), Guinea grass (*P. maximum*), giant star grass (*Cynodon plestostachyon*), groundnut (*A. hypogaea*), pigeon pea (*C. cajan*), *Crotolaria retusa*, *Centrosema* sp., *Calopogonium* sp., *Pueraria* sp., *S. gracilis*, and cowpea (*V. unguiculata*), all of which were obtained locally.

In April 1979, five seeds or cuttings of each cover plant were planted in 10-L clay pots filled with steam-sterilized sandy loam. The soil was inoculated with 10 000 eggs of *M. incognita* race 2. The experiment was a randomized complete block design with five replications.

The cover plants were uprooted after 1 year and the roots rated for galls according to Sasser and Taylor (1978) on a scale of 0–5; sodium hypochloride was used to extract eggs from 2-g samples of the roots of each plant. Yam (*Dioscorea rotundata*) setts, 120 g, were planted in each pot and harvested after 7 months. The degree of galling on the tubers was recorded (0 = 0, 1 = 1–2, 2 = 3–10, 3 = 11–30, 4 = 31–100, and 5 = > 100 galls).

The site of the field experiment is naturally infested with root-knot nematode, *M. incognita* race 2. The land was cleared and plowed in the early rainy season, 1978. Each plot, 10 m × 8 m, was bounded with soil to check movement of

Table 1. Root-gall indices and number of nematode eggs or larvae recovered from root and soil samples.[a]

	Glasshouse experiment			Field experiment		
	Root-gall indices			Root-gall indices		Larvae/ 200 mL soil
Cover plant	Cover plant	Yam	Eggs/2-g roots	Tomato	Yam tubers	
Guinea grass	1.0b	1.2b	58b	1.0c	2.0b	93bc
Star grass	1.6b	4.0a	286a	2.0b	3.0ab	298a
Crotolaria	0.0c	0.0c	0d	1.0c	1.0c	48dc
Centrosema	1.0b	1.0b	0d	1.0c	1.0c	67dc
Calopogonium	5.0a	3.8a	300d	4.0a	4.0a	456a
Cowpea (Ife Brown)	5.0a	4.0a	96b	3.6a	2.8ab	317a
Groundnut	0.0c	0.0c	0d	1.0c	1.0c	88bc
Pigeon pea	5.0a	5.0a	240a	4.2a	4.0a	300a
Pueraria	5.0a	5.0a	318a	4.4a	4.2a	515a
Stylo	0.0c	0.0c	0d	1.0c	1.0c	50dc
Aspilia	1.0b	1.0b	32cb	1.0c	1.0c	68c
African marigold	0.0c	0.0c	0d	1.0c	0.0d	32d
Eupatorium	1.0b	1.8b	50b	2.0b	2.2ab	133bc
French marigold	0.0c	0.0c	0d	1.0c	0.0d	24d

[a]Means in each column followed by same letter do not differ significantly according to Duncan's multiple-range test ($P = 0.05$).

rainwater, which can spread nematodes from plot to plot. The seeds or cuttings of the cover plants were planted in the plots in a randomized complete block, with five replications. The plots were kept free from weeds, and the annual plants were replanted the next year.

After 2 years, the cover plants were cleared and the plots hand ridged. Yam setts of *D. rotundata* cv. Igwe were planted, and soil samples were collected from each plot — 400 mL for bioassay (Prot and Netscher 1978) and 200 mL for nematode extraction by the modified Baermann funnel technique (tray method). Yam tubers were harvested after 7 months and scored for root galls. A tomato plant was grown in the same way as an indicator.

Results and Discussion

In the glasshouse experiment, no galls were observed on roots of *Crotolaria*, groundnut, stylo, African marigold, or French marigold (Table 1). The apparent immunity of these plants to *M. incognita* race 2 had been reported elsewhere (Peacock 1957; Ahuja and Arora 1980). Plants found highly resistant were *Centrosema*, guinea grass, *Eupatorium* (Siam weed), and *Aspilia*. Root-gall indices on the cover plants and yam test plant ranged between 1.2 and 1.8. Root-knot-nematode eggs recovered from 2-g root samples were relatively few (Table 1). The numbers of galls also suggested that giant star grass was resistant to the nematode; however, the number of eggs recovered from the root sample and the gall index of the yam was comparable with those of plants rated highly susceptible.

Plants found highly susceptible were *Calopogonium*, cowpea, pigeon pea, and *Pueraria*. Although there was considerable reproduction of root-knot nematode on *Pueraria* and giant star grass, foliar growth was not affected. In the field experiment, the findings were similar (Table 1), strongly suggesting that *Calopogonium*, cowpea, pigeon pea, and *Pueraria* should not be planted in fallow land intended for yam production, where root-knot nematodes are problems. Although Adeniji and Chheda (1971) found *Cynodon* sp. to be resistant to *M. incognita*, in both the greenhouse and the field trial, *C. plectostachyon* (giant star grass) was found to be susceptible in this study. Total number of nematode-free tubers harvested decreased, in order, from plots of French marigold, *Eupatorium*, African marigold, stylo, groundnut, *Crotolaria*, guinea grass, *Centrosema*, and *Aspilia* (Table 1).

As cost and side effects militate against use of nematicides in tropical areas, more attention should be paid to finding and breeding resistant plant varieties to parasitic nematodes. However, some resistant plants in fallow lands like Siam weed and guinea grass could constitute serious weed problems for a following crop. Cover plants such as stylo, *Centrosema*, *Aspilia*, groundnut, and marigold could be used to reduce the root-knot nematode population and to restore the soil fertility for yam production.

SURVIVAL OF *BOTRYODIPLODIA THEOBROMAE* IN YAM TISSUES

B.I. ADERIYE AND S.K. OGUNDANA[1]

We investigated persistence of *Botryodiplodia theobromae*, a yam-rot pathogen, and found that the fungus survived in the stem for 6 months; in the tubers for more than 8 months, and in the leaves for only 3 months. It was also viable for at least 10 months in sterile soil samples inoculated with infected yam tuber pieces.

Although considerable interest has been shown in *Botryodiplodia theobromae*, little, if any, work has been done to show its continued existence after harvest. The fungus has been recorded as a storage-rot pathogen by others (Dade and Wright 1931; Okafor 1966; Adeniji 1970; Ogundana et al. 1970), but its survival after the crop's harvest has not been studied. We examined the continued presence of the yam pathogen from one cropping season to another in the various tissues of the host (*Dioscorea* spp.) including the leaf, stem, and tuber.

MATERIALS AND METHODS

Botryodiplodia theobromae was grown on potato dextrose agar (PDA) in aseptic conditions for 12 days at 25°C under continuous light (Ekundayo and Haskins 1969). A suspension of pycnidiospores from the 12-day-old culture was made with sterile, distilled water and filtered through nonabsorbing cotton wool, final concentration of the spore suspension being approximately 1.6×10^6/mL.

Leaves, stem cuttings, and tubers were washed with tap water, surface-sterilized with 95% alcohol, and rinsed three times with sterile distilled water. These tissues were then infested with the spore suspension and stored in sterile conditions.

At monthly intervals, 1 g of the infected tissues was comminuted in sterile distilled water, serially diluted (Anwar 1949), and plated onto PDA. The plates were incubated at 28°C until fungal colonies appeared and could be counted.

Several portions of infected yam tubers, leaves, and stems were placed in plastic-net bags (15 cm × 15 cm; 12 mesh/cm) (Nyvall and Kommedahl 1970). Bags containing fragments from each of the tissues were buried at three different soil depths (10, 30, and 60 cm) and examined monthly. The soil was examined periodically for the pathogen's presence.

Sterile and unsterile samples of two different soils were inoculated with 1-cm^3 pieces of infected yam tuber to serve as food bases (Turner 1960). At intervals, portions of the infected food base were weighed, comminuted, and plated on 10 mL molten PDA.

Table 1. Monthly sampling[a] of yam tissues for *Botryodiplodia theobromae* under laboratory conditions, 1982.

Sampling date	Fungal colonies ($\times 10^2$) in 1 g infected tissu[b]		
	Leaf	Stem	Tuber
24 February	35	46	50
24 March	26	34	42
21 April	9	28	38
19 May	0	24	32
16 June	0	12	28
14 July	0	6	20
11 August	0	0	16
8 September	0	0	10

[a]Each value is a mean of three replicates in each of the host tissues.

[b]Colonies were counted after 5 days of incubation in all samplings.

[1] Department of Microbiology, University of Ife, Ile-Ife, Nigeria.

Table 2. Fungal colonies[a] ($\times 10^2$) of *B. theobromae* obtained from finely comminuted food bases, 1982.

Soil type	Date of sampling (day/month)								
	24/2	24/3	21/4	19/5	16/6	14/7	11/8	8/9	6/10
Virgin									
Sterile	54	49	46	42	36	29	42	38	36
Unsterile	59	50	42	37	28	21	16	9	4
Farm									
Sterile	62	50	38	27	18	4	0	0	0
Unsterile	55	39	24	10	0	0	0	0	0

[a]Each value is a mean of three replicates.

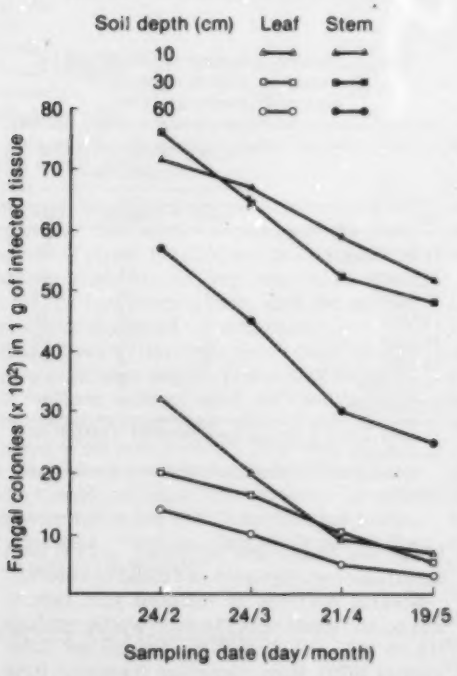


Fig. 1. *Fungal colonies surviving in yam tissues at different soil depths and sampling times.*

Results and Discussion

The fungus survived in the tuber for the whole 8 months of the experiment, in the stems for 6 months, and in the leaves for 3 months (Table 1). More colonies were obtained from the tuber than from the other yam tissues, the fungus being a tuber-rot pathogen. Its ability to degrade and utilize the carbohydrate of the tuber (Ogundana et al. 1971) may account for its longer survival in these tissues.

The study of the survival of *B. theobromae* in the buried tissues lasted only 4 months (24 February–19 May 1982) because the rains came early and altered the conditions of the experiment. However, the pathogen survived at the different soil depths for the full 4 months.

More isolates of the yam pathogen were obtained from the buried, infected stems than from the leaves at the different soil depths (Fig. 1). The fungal load at 10 and 30 cm in the infected stems beneath the soil was the highest throughout the period. The fungal count was low at 60 cm underground in both the stem and the leaf and decreased with time in both yam tissues. At 60 cm, the poor survival of *B. theobromae* may have been caused by competition from other fungal colonies (*Aspergillus*, *Fusarium*, and *Trichoderma*) that were isolated from the leaves (Hudson 1968).

Botryodiplodia theobromae in tuber pieces was more likely to survive in virgin than in farm soil (Table 2). In both sterile and unsterile virgin soil, the fungus survived throughout the 9 months of the experiment, although there were few colonies in the unsterile soil in the final 2 months. Survival of the fungus was shortest (4 months) in the unsterile farm soil and was only 6 months in the sterile farm soil.

The finding that *B. theobromae* survived 9 months in the yam tissues is similar to the results of Nyvall and Kommedahl (1970) who showed that *Fusarium moniliforme*, another yam-rot pathogen (Ogundana et al. 1970), survived in corn tissues for 8 months. In other words, the pathogen can tide over unfavourable periods on the host tissues for a period longer than normal yam storage in Nigeria (usually 7 months from October to early April).

VARIABILITY IN THE CHEMICAL COMPOSITION OF YAMS GROWN IN CAMEROON

T. AGBOR EGBE AND S. TRECHE[1]

We analyzed 98 cultivars belonging to eight yam species for mineral, protein, lipid, sugar, and cell-wall constituents. For most of the nutrients, intraspecific variability was as high as interspecific variability, but significant differences in the average values per species were found between *Dioscorea alata*, *D. dumetorum*, and the *D. cayenensis–D. rotundata* complex.

Several workers have shown the great variability that can exist between yams of different species. Busson (1965) compared the chemical composition of eight species of yam collected in different parts of West Africa. He observed important differences in the contents of crude protein (5.3–11.9 g/100 g), total carbohydrates (53.3–91.0 g/100 g), nondigestible carbohydrates (4.9–51.7 g/100 g), and calcium (0.014–0.024 g/100 g). Martin and Thompson (1971) insisted on the differences in crude protein content.

Other workers have been interested not only in the interspecific but also in the intraspecific variability in the chemical composition of yams. Baquar and Oke (1976, 1977) determined crude protein and mineral contents of about 60 samples belonging to 6 different yam species; the samples were collected from markets in Nigeria but were not well classified into different cultivars. Results showed that important variations, though not statistically tested, probably exist between species, and, in addition, that variations between samples within a species are also high. Similarly, using principal-component analysis based on amino-acid composition of 46 cultivars belonging to 5 yam species, Splittstoesser et al. (1973a) demonstrated wide intra- and interspecific diversity in amino-acid composition.

Earlier studies in our laboratory (Treche and Guion 1980) were dedicated to the differences in nutritional potentialities of the main yam species grown in Cameroon. This paper contains part of the results of a study on 98 cultivars agronomically classified (Lyonga and Ayuk-Takem 1982) belonging to 8 species. The objectives of our study were to compare intra- and interspecific variability in chemical composition, to assess nutritional value of cultivars, and to give references for clonal selection.

MATERIALS AND METHODS

From 1977 to 1982, we collected 98 samples from multiplication plots of the Institute of Agronomic Research throughout Cameroon. The samples corresponded to the descriptions by Lyonga and Ayuk-Takem (1982): *D. alata*, 23 samples; *D. bulbifera*, 11; *D. cayenensis*, 18; *D. dumetorum*, 23; *D. esculenta*, 6; *D. liebrechtsiana*, 2; *D. rotundata*, 9; and *D. schimperiana*, 6. For each sample, stored less than a week, tubers were weighed, peeled, washed, dried *in vacuo* at < 60°C, and ground in a "whiley" mill to pass through a 0.5-mm sieve.

We noted flesh colour and conducted chemical analyses to determine the contents of dry matter, ash, and crude protein; lipid by soxhlet extraction with petroleum ether; starch by the glucoamylase method (Thivend et al. 1965); total soluble sugars colorimetrically by the anthron method (Loewus 1952) after two hot extractions and one cold extraction by 80% ethanol; free glucose, fructose, and sucrose in 80% ethanol extract as proposed by Johnson et al. (1964); nondigestible carbohydrates by the formic-acid technique of Guillemet and Jacquot (1943); acid detergent fibre (lignocellulose) and neutral detergent fibre (lignocellulose and hemicellulose) by the procedures of van Soest (1963) and van Soest and Wine (1967); pentosans by the aniline–acetate colorimetric method of

[1] Food Studies Laboratory, Centre of Nutrition, General Delegation for Scientific and Technical Research, Yaounde, Cameroon.

Table 1. Dry matter, starch, cell-wall constituents, minerals, protein, lipids, and energy content of eight yam species.

	D. alata	*D. bulbifera*	*D. cayenensis*	*D. dumetorum*	*D. esculenta*	*D. liebrechtsiana*	*D. rotundata*	*D. schimperiana*
Samples	23	11	18	23	6	2	9	6
Dry matter (% of fresh peeled tuber)								
Average ± SE	24.4 ± 1.2	28.8 ± 0.9	32.6 ± 1.0	23.2 ± 0.6	29.7 ± 1.2	36.1	33.4 ± 1.5	23.0 ± 0.9
Range	14.1 – 35.1	24.8 – 35.1	23.5 – 40.2	19.0 – 28.3	24.5 – 30.8	35.9 – 36.3	26.3 – 39.5	19.4 – 25.6
Starch (%, dry weight basis)								
Average ± SE	72.6 ± 1.4	72.9 ± 0.7	80.0 ± 0.7	70.5 ± 0.7	70.4 ± 1.2	80.4	80.2 ± 0.9	71.1 ± 3.2
Range	60.2 – 82.1	69.8 – 78.6	76.9 –85.3	61.7 – 75.5	66.3 – 73.4	79.7 – 81.1	77.4 – 84.1	56.3 – 78.1
Acid-detergent fibre (%, dry weight)								
Average ± SE	3.4 ± 1.0	3.5 ± 0.6	2.6 ± 0.7	5.5 ± 0.3	2.7 ± 0.1	2.0	2.4 ± 0.1	3.5 ± 0.5
Range	2.1 – 5.0	3.0 – 5.0	1.2 – 4.1	3.4 – 7.6	2.3 – 3.1	1.9 – 2.1	2.1 – 2.7	2.4 – 5.8
Neutral detergent fibre (%, dry weight)								
Average ± SE	4.9 ± 1.5	3.5 ± 0.7	3.3 ± 1.0	5.2 ± 0.4	2.6 ± 0.2	2.4	2.6 ± 0.4	4.6 ± 1.0
Range	2.8 – 8.8	2.9 – 5.2	1.7 – 5.0	3.0 – 8.4	2.4 – 3.2	2.4 – 2.5	1.6 – 4.4	2.0 – 8.6
Phosphorus (g/100 g)								
Average ± SE	0.116 ± 0.005	0.128 ± 0.006	0.093 ± 0.004	0.161 ± 0.005	0.089 ± 0.008	0.052	0.094 ± 0.005	0.112 ± 0.010
Range	0.068 – 0.183	0.100 – 0.154	0.065 – 0.125	0.118 – 0.201	0.063 – 0.114	0.050 – 0.053	0.067 – 0.114	0.061 – 0.140
Calcium (g/100 g)								
Average ± SE	0.029 ± 0.005	0.023 ± 0.007	0.015 ± 0.001	0.042 ± 0.003	0.025 ± 0.003	0.023	0.018 ± 0.003	0.045 ± 0.010
Range	0.014 – 0.049	0.020 – 0.028	0.008 – 0.028	0.023 – 0.073	0.019 – 0.032	0.020 – 0.026	0.011 – 0.036	0.020 – 0.084
Potassium (g/100 g)								
Average ± SE	1.35 ± 0.06	1.17 ± 0 03	0.087 ± 0.05	1.05 ± 0.07	1.26 ± 0.05	0.76	1.07 ± 0.10	1.28 ± 0.05
Range	0.85 – 1.91	0.99 – 1.36	0.57 – 1.45	0.49 – 2.03	1.15 – 1.48	0.70 – 0.82	0.73 – 1.74	1.15 – 1.45
Magnesium (g/100 g)								
Average ± SE	27.2 ± 0.9	24.5 ± 1.5	23.4 ± 0.7	57.1 ± 2.7	37.4 ± 2.4	29.0	52.8 ± 5.0	40.8 ± 4.6
Range	19.5 – 35.5	22.4 – 25.8	19.6 – 29.4	30.9 – 114.5	28.9 – 44.6	27.9 – 30.1	26.7 – 72.5	30.1 – 58.4
Iron (g/100 g)								
Average ± SE	4.30 ± 0.78	4.39 ± 0.48	2.92 ± 0.32	6.85 ± 0.85	3.00 ± 0.34	4.89	5.47 ± 0.82	3.42 ± 0.34
Range	0.94 – 17.6	2.01 – 7.53	0.70 – 5.90	2.18 – 18.7	1.69 – 3.83	3.83 – 5.94	2.46 – 10.27	2.68 – 4.75
Zinc (g/100 g)								
Average ± SE	1.48 ± 0.12	1.76 ± 0.07	1.39 ± 0.08	1.88 ± 0.08	2.11 ± 0.19	2.71	1.30 ± 0.16	2.38 ± 0.32
Range	0.68 – 2.47	1.40 – 2.12	0.73 – 2.02	0.89 – 2.98	1.63 – 2.65	2.59 – 2.83	0.78 – 2.16	1.42 – 3.48
Copper (g/100 g)								
Average ± SE	0.87 ± 0.04	1.47 ± 0.05	0.94 ± 0.06	1.02 ± 0.10	1.14 ± 0.06	0.96	1.14 ± 0.17	1.65 ± 0.14
Range	0.53 – 1.28	1.25 – 1.79	0.43 – 1.36	0.61 – 2.18	0.88 – 1.30	0.96 – 0.96	0.73 – 2.16	1.19 – 2.13
Sodium (g/100 g)								
Average ± SE	8.8 ± 1.0	13.9 ± 1.7	13.0 ± 0.9	15.9 ± 0.9	3.9 ± 0.9	2.7	12.9 ± 1.5	2.0 ± 0.2
Range	3.9 – 19.3	11.6 – 21.6	7.3 – 18.8	8.1 – 23.4	3.8 – 4.0	2.4 – 2.9	11.0 – 16.7	1.4 – 3.0
Crude protein (%, dry weight)								
Average ± SE	8.24 ± 0.66	6.17 ± 0.32	6.08 ± 0.33	9.64 ± 0.30	5.10 ± 0.41	3.17	7.02 ± 0.54	7.66 ± 0.55
Range	4.72 – 15.84	4.62 – 8.45	3.55 – 8.35	7.36 – 13.21	4.06 – 6.46	3.12 – 3.22	4.31 – 8.88	5.94 – 8.87
Total lipids (%, dry weight)								
Average ± SE	0.24 ± 0.02	0.24 ± 0.02	0.21 ± 0.03	0.33 ± 0.05	0.25 ± 0.06	0.82	0.17 ± 0.05	0.20 ± 0.02
Range	0.10 – 0.40	0.14 – 0.36	0.10 – 0.50	0.07 – 0.63	0.11 – 0.46	0.72 – 0.92	0.07 – 0.53	0.15 – 0.26
Energy[a] (cal/100 g)	383	383	387	381	388	396	385	383

[a]Calculated from specific energy factors given by Merrill and Watt (1955).

Cerning and Giulbot (1973); phosphorus colorimetrically by the phosphovanadomolybdate ammonium method; iron by the orthophenanthrolene colorimetric method; calcium, potassium, sodium by Eppendorf flame photometer (Gueguen and Rombauts 1961); magnesium, zinc, and copper by Varian atomic absorption spectrometer.

Results and Discussion

Average weight of tubers from the eight species differed markedly. In fact, we could distinguish species by the number of tubers per plant — one or two: *D. alata*, *D. cayenensis*, *D. liebrechtsiana*, *D. rotundata*, *D. schimperiana*; several tubers jointly attached per plant: *D. dumetorum*; and distinct small tubers: *D. esculenta*; or bulbils: *D. bulbifera*.

Average peeling losses varied between 17.1% and 33.3%, depending on the species. Within one species, variations were very high (11.8–51.3% for *D. dumetorum* yam samples).

The flesh was most commonly white or yellow, but some cultivars of *D. alata* were distinctly violet and those of *D. schimperiana* orange.

The species could be divided into those with low (23–25%) dry-matter content (*D. alata*, *D. dumetorum*, *D. schimperiana*) and high (32–37%) dry-matter content (*D. cayenensis*, *D. liebrechtsiana*, *D. rotundata*), with *D. esculenta* and *D. bulbifera* having intermediate values (Table 1). Within *D. cayenensis*, cultivar C169, which has been selected as agronomically elite (Lyonga and Ayuk-Takem 1982), was the only one with low dry-matter content. Variations within *D. alata* were more important than those within the other species.

In mineral contents, ratios between the lowest and highest average by species varied between 1 : 2 and 1 : 3 except for sodium with a ratio of 1 : 8 found between several species (Table 1). Within one species, the ratio did not exceed 1 : 4 for most of the minerals. Intraspecific variability for P was lower than for other minerals, whereas Na and Fe had higher variability. The highest Fe values were probably caused by contamination of the samples during drying. Our results on K and Zn contents in *D. alata*, *D. dumetorum*, and *D. rotundata* were similar to those of Baquar and Oke (1977), but other values differed systematically.

Starch contents were within the range 70.4–72.9% except for *D. cayenensis*, *D. liebrechtsiana*, and *D. rotundata*, which had values greater than 80.0% (Table 1). The intraspecific variability in the low-starch species was higher than in the others.

Dioscorea esculenta and *D. liebrechtsiana* had comparatively high soluble sugars. The other species did not differ markedly from one another, but there was a high intraspecific variability, mostly within *D. alata* species.

For all the cell-wall constituents studied (Table 1), *D. dumetorum* had the highest average values, then *D. alata* and *D. schimperiana*. The lowest were peculiar to *D. rotundata* and *D. liebrechtsiana*. The high values for some *D. dumetorum* cultivars probably reflected the hardening phenomenon (Treche and Delpeuche 1982), which can occur just hours after harvest. As has been shown by Brillouet et al. (1981), the proportions of different cell-wall constituents, especially lignocellulose and hemicellulose, were not the same in all the yam species. Average hemicellulose content was unnoticeable for *D. dumetorum* tubers, whereas it reached 0.7% and 1.6% for *D. cayenensis* and *D. alata*, respectively.

Dioscorea dumetorum and *D. alata* had the highest average crude protein (Table 1); *D. liebrechtsiana* and *D. esculenta*, the lowest. High crude-protein content seems to be characteristic of *D. dumetorum* tubers, as the average value of 24 new varieties bred in Cameroon attained 10.2% (Pfeiffer and Treche, unpublished data). Nevertheless, intraspecific variability of crude protein seems to be at least as high as interspecific variability. On a fresh-weight basis, *D. rotundata*, *D. dumetorum*, *D. alata*, and *D. cayenensis* were distinct from the others by having a protein content more than or equal to 2.0%.

Lipid content was low except in *D. liebrechtsiana* and some cultivars of *D. dumetorum*. The range of ash content was not wide.

The energy content (Table 1) did not vary much because of the small absolute variation in lipid and ash, with *D. rotundata*, *D. cayenensis*, and *D. liebrechtsiana* having the highest calorific value.

Conclusion

Dioscorea cayenensis and *D. rotundata* were shown to be closely related. In fact, certain researchers (Martin and Rhodes 1978; Miege 1982) have grouped cultivars of these species into a *D. cayenensis–D. rotundata* complex. Using the Student's t-test for each nutrient, we found no significant differences between the two spe-

cies except for total soluble sugars, nondigestible carbohydrates, Fe, and Mg.

Taking into account the characteristics in the chemical composition of the different species, especially the dry-matter content, we believe that cultivars of the *D. cayenensis–D. rotundata* complex are best for consumption fresh, whereas *D. dumetorum* and perhaps *D. alata* could be used in yam flour.

MINERAL CONTENT OF YAM TUBERS: RAW, BOILED, AND AS FLOUR

A. BELL[1]

The zinc, copper, iron, manganese, magnesium, calcium, and total phosphorus content of 20 yam varieties belonging to 7 edible species, i.e., *Dioscorea rotundata*, *D. cayenensis*, *D. alata*, *D. esculenta*, *D. liebrechtsiana*, *D. schimperiana*, and *D. dumetorum*, was determined. The tubers were analyzed before and after being boiled and being converted into flour. The mineral composition of the tuber after treatment varied little from that before treatment. The greatest loss recorded was in magnesium and phosphorus as a result of boiling the peeled tuber.

The calcium, phosphorus, and iron content of yams has been discussed by several authors, including Winton and Winton (1935); Intengan et al. (1954); Platt (1962); Ingram et al. (1962); Oke (1965); and Pele and Le Berre (1966). More recently, Baquar and Oke (1977) reported the phosphorus, calcium, magnesium, potassium, sodium, zinc, copper, manganese, and iron levels found in 58 cultivars representing 6 yam species consumed in Nigeria.

Few studies provide the mineral composition of ready-to-eat yams, i.e., either the cooked or converted product. Composition tables of the Food and Agriculture Organization of the United Nations (FAO 1970) give the levels of calcium, phosphorus, iron, and some vitamins in yam flour along with the overall composition but do not supply any further details on the species used. The purpose of this study is to report the mineral composition of 20 edible yam varieties in raw, boiled, or converted form.

MATERIALS AND METHODS

Twenty cultivars from seven edible yam (*Dioscorea* spp.) species were studied. They included *D. rotundata* (3), *D. cayenensis* (3), *D. alata* (5), *D. esculenta* (3), *D. liebrechtsiana* (2), *D. schimperiana* (1), and *D. dumetorum* (3).

All the tubers, with the exception of *D. alata* specimens provided by the Njombé agricultural station in December 1981, were supplied by the Ekona agricultural station in October–December 1980. The tubers were grown without fertilizers and harvested at maturity, i.e., after 9 months. They were then conveyed to Yaounde within a day and kept at ambient temperature for a maximum of 3 weeks (1 week for *D. dumetorum*).

Four identical groups of tubers were made up from the one lot, each tuber being cut lengthwise. The first group was reserved for raw product analyses, the second for analyses on the boiled product, and the third and fourth for flour tests (Table 1). Each type of preparation was repeated at least three times.

Except for the dried chips used for preparing the flour, the raw and treated tubers were vacuum-dried in the oven at 45°C. They were then ground to pass through a 1-mm-mesh sieve. Dry

Table 1. Methods of preparation for analyses of mineral content of yam.

	Temperature (°C)	Mean time for 1 kg tuber (min)
Peeled and boiled	97	30
Unpeeled *D. dumetorum*, quartered and boiled	97	90
Preparation of the flour		
Peeled, sliced, and washed in boiling water	97	1.5
Oven-dried	65	—[a]

[a]Overnight.

[1] Centre for Nutrition, General Delegation for Scientific and Technical Research, Yaounde, Cameroon.

matter and mineral content determinations were carried out in two trial samples.

The mineral content was determined from the hydrochloric extract of ashes obtained by incinerating the tubers at 450°C for 48 h.

The determinations carried out were:

- Calcium by flame photometry;
- Total phosphorus by the Vanadate colorimetric method (Stuffins 1967);
- Iron by the O-phenanthrolene method; and
- Copper, manganese, magnesium, and zinc by atomic absorption spectrophotometry.

Duncan's multiple range test (1955) was used to analyze the significance of variations in mineral content observed after boiling and conversion into flour in relation to values recorded in the raw product.

Results and Discussion

The mineral content of yams varies (Table 2) according to species. Yams may supply a sub-

Table 2. Mineral content of yam tubers: raw, boiled, and as flour.[a]

	Zn (ppm)	Cu (ppm)	Fe (ppm)	Mn (mg/100 g)	Mg (mg/100 g)	Ca (mg/100 g)	P (mg/100 g)
D. rotundata							
Bonakanda (R971)	17.3	6.4	15.0	10.5	51.9	24.3	135
Boiled[b]	18.2	6.2	12.6**	10.4	41.9**	23.0	121**
Flour[c]	21.6**	5.8**	14.0**	11.0	45.3**	19.9*	122**
Ogoja (R670)	12,2	4.4	11.4	6.9	49.9	25.4	71
Oshie (R871)	11.1	4.4	11.6	13.1	51.9	30.1	81
D. cayenensis							
Dschang (C 1170)	9.5	3.8	18.6	4.4	44.4	14.3	89
Boiled	11.8**	3.4	15.4**	4.7	38.6**	14.6	79*
Flour	10.5	3.3	18.7	3.6	37.4**	13.4	82
Beep (C 1870)	10.0	4.4	14.5	4.0	55.0	21.0	86
Boiled	8.9	4.3	11.1**	3.9	50.6*	18.4	79*
Flour	8.6*	4.0*	15.7**	4.8	52.5	19.5	82
Bafang (C 269)	7.4	3.2	19.4	4.2	38.0	21.5	91
D. alata							
Pacala station (A 1372)	11.3	4.8	11.6	1.0	65.7	18.1	168
Boiled	11.4	4.5	11.3	1.6	59.9**	18.6	159
Flour	10.6	4.5	24.4**	1.9	62.1*	17.5	164
Guadeloupe (A 1572)	8.4	3.6	12.8	1.8	75.2	28.9	140
Boiled	9.5	3.5	11.9**	2.4	67.6**	31.7	130*
Flour	9.3	4.0*	36.8**	3.6	73.7	31.9	141
Gaana (A 1872)	8.3	4.3	14.3	2.0	58.8	19.9	138
Boiled	8.3	4.0	14.2	2.0	52.7**	17.7	126*
Flour	8.3	4.3	19.1**	2.3	52.4**	18.4	127*
Guadeloupe (A 3778)	12.0	4.9	13.0	3.0	72.4	25.2	177
Boiled	12.4	5.0	14.6**	2.9	69.0*	24.6	159**
Flour	11.4	4.8	19.2**	3.2	70.1	22.5	166*
Guadeloupe (A 3878)	14.0	4.6	14.2	2.3	67.1	26.7	190
Boiled	14.9	3.8	12.8**	2.0	58.2**	25.6	170**
Flour	13.2	4.3	44.8**	2.9	61.8**	26.2	189
D. esculenta							
Fiango (E 171)	15.8	5.3	12.1	3.0	74.8	30.4	181
Boiled	22.7**	5.4	12.6	3.6	68.7**	30.2	167**
Flour	17.8**	5.9*	11.3*	3.6	77.5	30.2	179
Bombe (E 272)	17.6	6.6	20.9	2.3	81.9	32.7	172
Boiled	16.6	6.3	16.9**	2.3	76.4**	31.5	153**
Flour	18.7	6.6	28.3**	3.0	80.4	36.2	163

continued

Table 2 continued

	Zn (ppm)	Cu (ppm)	Fe (ppm)	Mn (mg/100 g)	Mg (mg/100 g)	Ca (mg/100 g)	P (mg/100 g)
Ibadan (E 373)	17.0	5.8	16.1	3.4	84.8	37.3	178
Boiled	17.4	5.7	15.8	3.2	80.2*	41.4*	169
Flour	18.0	6.0	24.8**	3.7	85.3	41.5*	177
D. liebrechtsiana							
Ebolowa (L 170–L 270)	10.1	3.5	16.0	1.5	47.2	18.1	96
Boiled	12.4**	3.4	13.5**	1.3	38.9**	17.8	82**
Ebolowa (L 170)	12.9	3.6	26.9	1.8	44.3	19.3	81
Ebolowa (L 270)	8.7	3.4	10.5	1.5	48.6	17.5	103
D. schimperiana							
Dschang	21.0	6.5	21.3	33.8	86.0	47.7	125
D. dumetorum							
Jakiri (D 569)	24.4	6.3	26.4	13.5	75.0	42.9	211
Boiled	26.8**	5.6**	146.2**	21.2**	70.1**	41.1	190**
Flour	24.3	6.3	24.1**	13.5	76.2	39.8	195**
Local	19.7	5.6	32.7	23.7	90.4	78.5	218
Boiled	24.9**	5.4	84.4**	31.0**	85.4**	85.1*	218
Flour	21.9**	5.7	29.3**	23.9	87.2*	77.8	194**
Muyuka (D 2075)	13.4	3.7	27.9	16.5	74.2	35.8	199
Boiled	15.0*	3.4	50.0**	19.7**	67.9**	43.4**	191
Flour	14.9*	3.5	34.7**	18.4*	66.7**	33.5	200

[a]Significance values: * = $P < 0.05$; ** = $P < 0.01$.

[b]All *D. rotundata*, *D. cayenensis*, *D. alata*, *D. esculenta*, and *D. liebrechtsiana* varieties were peeled before being boiled, whereas the three *D. dumetorum* varieties were not.

[c]Flour was obtained by washing the tuber in boiling water and drying it at 65°C.

stantial portion of the manganese and phosphorus requirements of adults, and, to a lesser degree, the copper, iron, and magnesium requirements as well (Table 3). *Dioscorea dumetorum* had the highest mineral content of all the species studied. Although these findings agree with the results reported by Baquar and Oke (1977), there were differences in the two studies with regard to the copper, manganese, and magnesium content of some species. In my study, lower copper levels were recorded in *D. rotundata*, *D. alata*, *D. esculenta*, and *D. dumetorum* but higher manganese levels in *D. rotundata* and *D. dumetorum* and higher magnesium levels in *D. alata* and *D. esculenta*.

Analyses were conducted for only a single variety of *D. schimperiana*, but it was comparable with *D. dumetorum*. The yams studied were poor in calcium and the average Ca/P ratio was close to 0.2.

For all minerals except calcium, yams, on average, are richer than cassava, new cocoyams (macabo), and sweet potatoes (FAO 1970; Cresta et al. 1976; Favier et al. 1977; Elkins 1979). Old cocoyams (taro) are on a par with the richest yam varieties. Although my findings are

Table 3. Average mineral supply per 200 g[a] of yam (% of adult requirements) (Passmore et al. 1974).

Species	Zn	Cu	Fe	Mn	Mg	Ca	P
D. rotundata	8	18	9	22	12	4	15
D. cayenensis	5	12	11	8	9	3	12
D. alata	4	11	6	3	11	3	18
D. esculenta	7	15	8	4	14	4	20
D. liebrechtsiana	6	13	13	4	11	3	15
D. schimperiana	8	14	9	45	13	5	12
D. dumetorum	7	11	13	24	12	5	20

[a]Estimate of average daily consumption per person, based on yam-production data for Cameroon (Minagri 1976).

based on only a small number of varieties, taro (or old cocoyam) seems to be even richer than yam in magnesium, zinc, and copper.

In the boiled, peeled product, the greatest loss recorded was for magnesium and phosphorus, which decreased by an average of 10% (Table 2).

Variations in the calcium and copper content were generally low and insignificant. Manganese and zinc levels were higher than in the raw yam, but differences, except in the case of zinc in some varieties, were slight. Differences in iron levels showed greater inconsistency. There was little mineral loss in boiled, unpeeled, and quartered *D. dumetorum* tubers but some increase in iron, manganese, and zinc levels (Table 2). With this preparation, variations were comparable with those recorded when yams were peeled, then boiled. Losses, however, were slighter (Table 2). This is not surprising, as the first step in converting yams into flour consists of washing peeled, sliced tubers in boiling water. There was a considerable increase in iron and manganese levels, but, in the case of manganese, the difference between the raw and prepared products was generally not significant. These increases were probably a reflection of contamination from the metal trays used during drying.

Conclusions

As a result of yam's manganese, phosphorus, copper, iron, and magnesium content, it could provide a substantial portion of the mineral requirements in western Africa where daily consumption may exceed 1 kg/person. Boiling and conversion into flour only slightly affect the mineral composition of yams. Studies are necessary, however, to determine the biological availability of these minerals before and after conversion in areas where the yam constitutes the staple food.

I wish to thank the agricultural research centres at Ekona and Njombé for supplying the yam tubers analyzed. My thanks also go to Abona and B. Hagbe for their valuable technical assistance.

INTRODUCTION OF FLOUR FROM *DIOSCOREA DUMETORUM* IN A RURAL AREA

G. MARTIN, S. TRECHE, L. NOUBI, T. AGBOR EGBE, AND S. GWANGWA'A[1]

We taught 25 village volunteers a simple method to produce flour from *Dioscorea dumetorum* tubers by drying precooked slices and grinding them in a diesel-powered mill. Enriched porridge and fufu prepared during a demonstration session were tasted, the latter with local sauces. The volunteers were then asked to feed their households flour, and, each week, we recorded the number of times the flour was eaten. After 12 weeks, results showed that all but three households ate the flour regularly. They thought it was good and, if available, could substitute for other flours used locally, especially for infant feeding. The flour processing was possible at the village level, and they recommended changes in some of the steps.

The study of the nutritional potentials of tropical roots and tubers continues to attract many researchers because these crops are major staples of the developing world. Criteria have been laid down for crop-improvement research, and these include potential yield, cost of production, the food and feed value of the crop, and the way the crop can be processed or otherwise used. The nutritional qualities of crops have not been accorded a high priority in the decision-making, and this might explain why *D. dumetorum* has not been as widely studied as other species. It grows readily on various soils, the yield being 3–7 times that of other widely grown yam species (Treche and Guion 1980), and both planting and harvesting can be mechanized. Nutritionally, it is superior to the commonly consumed yams, having high protein and mineral content (Baquar and Oke 1976, 1977; Treche and Guion 1979). Szylit et al. (1977), Bewa (1978), Treche and Guion (1980) have all shown that the starch grains are smaller, more soluble, and more digestible than those of other yam species. Unfortunately, the postharvest losses are large because, if the tubers are not cooked within a few days after harvest, they harden and are good only for planting. This hardening phenomenon has been described by Treche and Delpeuche (1982).

The Centre for Nutrition, Cameroon, has been carrying out comparative studies of the physicochemical and nutritional properties of several species and varieties of yams grown in the country, in collaboration with the agricultural research institute. From the results, *D. dumetorum* was selected not only for its nutritional qualities but because it has been neglected in attempts to process yam into more durable forms such as dried slices and flour. Yam flour from *D. rotundata* in the forms of "elubo" or "amala" . . . despite its colour . . . is being enjoyed as food in parts of western Nigeria. Other countries have produced yam flour from their yams (Jarmai and Montford 1968; Martin and Ruberte 1975b; Ciacco and D'Appolonia 1978). S. Treche and others (unpublished) have adapted one of the known methods to make flours from *D. dumetorum* and *D. rotundata*. Following tests for physicochemical and nutritional properties and acceptability among the centre personnel, we decided to try out the flour in a community. Our objectives were to determine whether a rural community would process the flour and eat it.

MATERIALS AND METHODS

Dioscorea dumetorum (Jakiri variety) setts were supplied by the Institute of Agricultural Research (IAR), Bambui. Village participants used their own farmland for planting and constructed stands by their houses for the special trays we provided.

The study was carried out in four villages in Mvolye 5–7 km from our centre. It was in three

[1] Centre for Nutrition, Institute for Medical Research and the Study of Medicinal Plants, General Delegation for Scientific and Technical Research, Yaounde, Cameroon.

phases: planting, January–March 1982; processing, November 1982–January 1983; and consumption, February–May 1983. The whole exercise was explained to 25 volunteers and a questionnaire was completed, detailing their yam planting and eating habits. On each farm, we chose a suitable site and demonstrated how to plant the setts in beds because the participants were more accustomed to planting on mounds.

When the participants had completed the land preparations, we supplied them with enough setts to plant their areas. We closely supervised planting, staking, and clearing. The yams were harvested over 4 weeks in 4–5 batches. Following each harvest, the yams were weighed and divided into three parts: one for drying in the village, the second for processing in the laboratory, and the third left to the planter to eat fresh and store for seeds. On the following morning, the yams were peeled, cut into 0.5-cm slices, boiled for 45 minutes, and spread thinly on the trays. The trays had to be taken in at night and whenever it rained for there was no one to protect them from thieves and animals. It took about 3–4 days for each batch to be well dried. We took samples for laboratory analysis, and the rest was packed in plastic bags. The dried yam slices were ground, sifted, and weighed at the centre. Each participant was given what he or she had dried, the good flour for human consumption and the chaff and poor samples for animal feed. The detailed analysis of the planting and transformation phases have been described in greater detail elsewhere (S. Treche et al. unpublished).

The consumption phase was preceded by a cookery–eating demonstration. Yam porridge was prepared with boiling water and sugar. Subsamples were enriched with either milk, egg, or groundnut paste. Cooking time was about 2–3 minutes. We cooked the yam fufu (foofoo mesol as the local women called it) by stirring the yam flour in a little boiling water and adding more water until preferred consistency was obtained (3–6 minutes). It was eaten with soups (Kelengkeleng, groundnut stew, and cassava leaf or Kpem) cooked by the participants. Everybody ate — children and adults including the researchers. We noted verbal and facial expressions of appreciation or disapproval.

The participants were asked to cook the flour at home and feed it to their families as often as they wanted and to try other local recipes. Two questionnaires were completed during this period, one to determine their attitudes toward the planting and processing and the other their consumption pattern.

Results and Discussion

The villages in Mvolye are within our community health project where medical students do field postings and researchers study the nutritional status of the community. Perhaps we were working with an enlightened and receptive group. They, also being on the outskirts of the city of Yaounde, may not be representative of a village. Nevertheless, yam flour is foreign to them. Their staples are cassava, plantains, cocoyams, and rice in descending order, and they eat lots of vegetables and palm oil. Food is cooked once a day in the mid-afternoon and is eaten as the main meal. Children eat leftovers during the rest of the day. The people are subsistence farmers, and they grow the first three staples and groundnuts. *Dioscorea dumetorum* and *D. rotundata* are grown but on a very small scale, about 10–50 setts; only two women grew more, mainly for sale.

In previous laboratory study, flours made from raw and precooked yam were dried both in an oven and in the sun. Palatability tests (S. Treche et al. unpublished) had shown that the oven- and sun-dried, precooked flours were preferable, and, as the process was intended for a village technology, the sun-drying method was more practical.

Before completing our first questionnaire, we had thought that the flour could become an adequate weaning food to substitute for porridge from cassava starch. To our surprise, yam — especially *D. dumetorum* — is taboo for children. The belief is that children will either be dumb or stammer if they eat yam before speech is established, i.e., about age 2 years. Imported infant foods are used, and the contents are not questioned. We went ahead with our project because we noticed that the belief was not shared by all and those who did believe were not too convinced.

The participants included 2 men, 2 teenaged girls, and 21 mothers, ages ranging between 18 and 72 years. Of these, 12 were younger than 35 years and 13 older; 4 had postprimary education, 17 had primary education, and 4 never had been to school. They were all farmers, but two were also secretaries and one a retired inspector of schools. Of the total, 20 planted yams regularly (*D. rotundata* and *D. dumetorum*), but none of them knew of any process to conserve *D. dumetorum*.

No participant planted *D. dumetorum* alone; of the 16 who planted both species, 12 planted equal quantities. The reasons given were:

Table 1. Yam setts distributed and yield per village.

Village	Setts			Yield (t/ha)
	Distributed (%)	Planted (%)	Weight (kg)	
Ahala	96.1	97.8	1.41	20.3
Nsimeyong I	78.0	—[a]	2.44	28.6
Nsimeyong II	80.0	89.2	1.31	14.1
Nsimeyong III	89.5	86.5	1.35	18.2

[a]Not determined.

Table 2. Frequency of flour consumption per week in the commmunity.

Week	February	March	April	May
1	0	11	13	16
2	7	11	15	11
3	7	7	16	7
4	6	19	10	0

- Yam setts were not readily available;
- Yam planting was too arduous and their soil was hard;
- *D. dumetorum* ("Isol") yielded more than *D. rotundata* ("Kkodo"), but, because the former could not be stored, only a few setts were planted; and
- For those who sold yams, *D. rotundata* fetched more money.

The *D. dumetorum* tubers are harvested as needed for food and cooked immediately, and *D. rotundata* tubers are all harvested at once and stored in a cool, shaded area. The participants consider the latter as food because it is available for longer periods than the former, which is considered a snack. They think *D. dumetorum* is good food but perhaps not as good as *D. rotundata*. The yields in our study were acceptable (Table 1), and the differences noted between villages might have been a reflection of variations in the sizes of the setts supplied as well as in the previous crops planted on the sites. The amount of flour obtained was 10.83% of the fresh weight of the tubers. The unacceptable dried samples were ground and mixed with chaff for animal feed. The dry-matter content was 86.7 g/100 g in the village flour compared with 90.2 g/100 g for the centre flour. The protein content was slightly higher in the village flour (7.19/100 g) than in the centre flour (6.9 g/100 g) and in the indigestible glucides (village, 3.23 g/100 g; centre, 2.67 g/100 g). These differences may reflect onset of hardening, with increase in cell wall content because of slow and uncontrolled drying.

In general, the participants felt that they could produce the flour at the village but would prefer to boil the tubers whole or in large pieces and then peel the thin skin before slicing. If possible, appliances should be made available. The drying was too dependent on the weather, and the trays had to be carried indoors to protect them from thieves and animals.

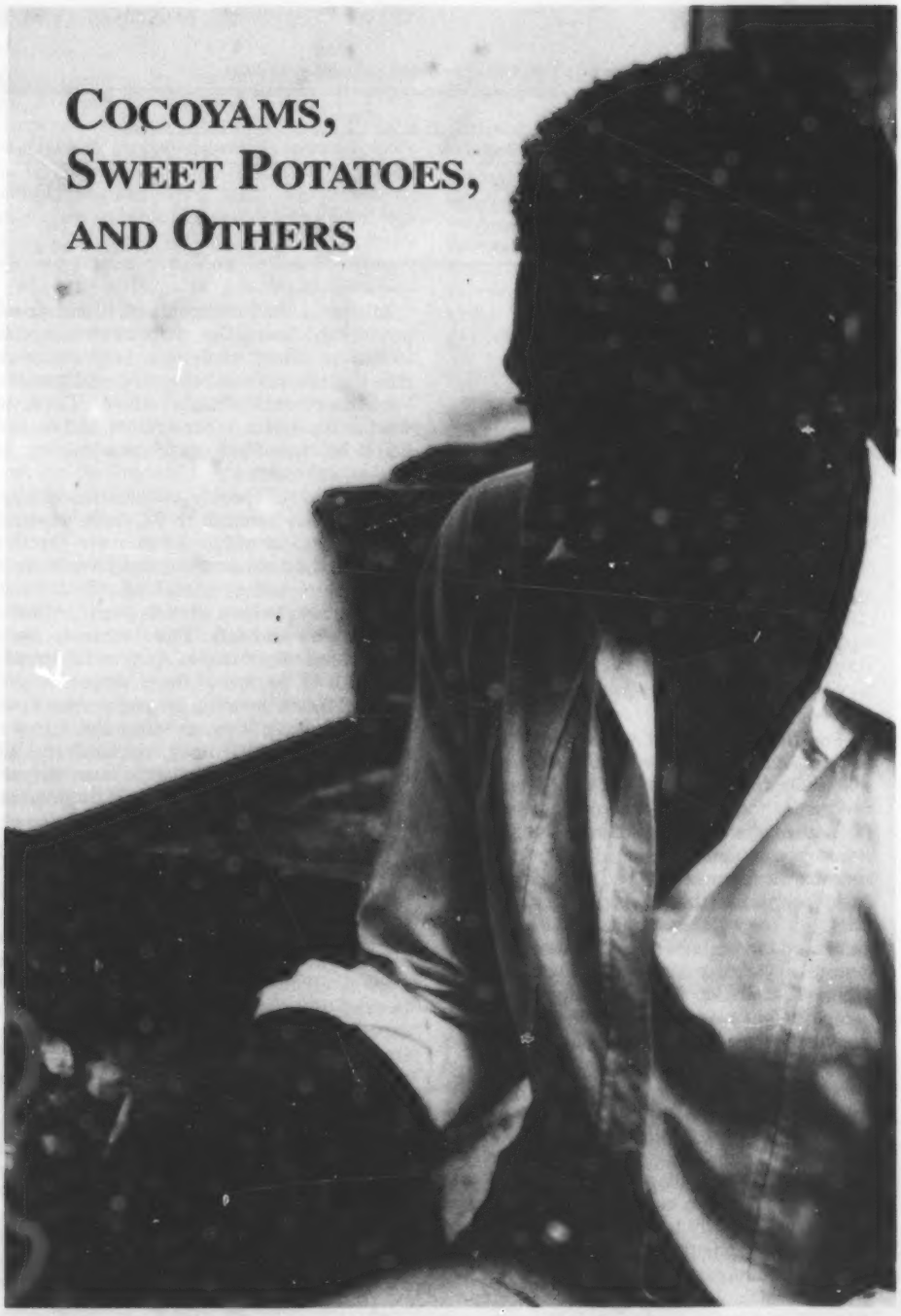
There were 137 people, of both sexes with ages ranging from 1 month to 78 years, in the 25 households, of which 3 never ate the flour (1 missed the demonstration and 2 would not eat it). In the remaining households, the flour was eaten once or twice a week as porridge (mainly by children) and fufu. Flour consumption increased from February to April and dropped in May (20, 48, 54, and 44 times, respectively, Table 2). The sweetened, enriched porridge (with groundnut paste, egg, or milk) and fufu were eaten 102 and 191 times, respectively. Kelengkeleng (*Corchorue alitarius*) was the most popular soup (50 times), followed by groundnut stew (44 times), cassava leaf (36 times), and okra (24 times). As the flour stock began to run out, it was reserved for children. It replaced some of their staples and was economical because small quantities were sufficient for meal preparation, with the flour swelling up considerably when mixed with liquid. Two disadvantages noted were a slightly bitter taste, which could be masked with sugar or soup, and a poor binding capacity, which could be improved with cassava starch. Some of the participants felt that, with time, they could get accustomed to the taste and texture.

During the 12 weeks, the flour was also used in Ekomba (yam flour, groundnut paste, and salt) and Koki (yam flour, palm oil, pepper, and salt) steamed in plantain leaves.

This pilot study shows that *D. dumetorum* flour can be processed in a rural community with simple trays and a grinding mill.

This study was made possible by the collaboration of the researchers in IAR, the village participants, and members of the nutrition centre.

Cocoyams, Sweet Potatoes, and Others

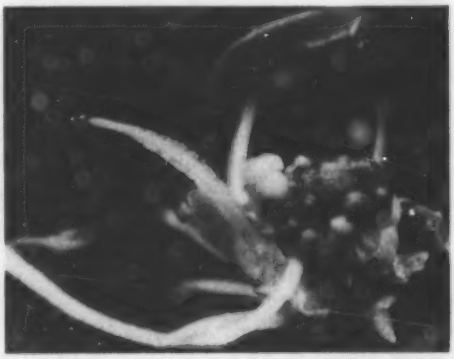


In-vitro methods for cocoyam improvement

E. Acheampong[1] and G.G. Henshaw[2]

We have multiplied cocoyam germ plasm through protocorm production in vitro, and the method can theoretically yield more than 1 million plants a year. Cultures have been stored in vitro on reduced nutrient media for 80 weeks or more under conditions close to ambient. The basic tissue-culture methods employed should eliminate diseases and viruses and enable international transfer of germ plasm.

Meristem culture is increasingly being used to eliminate diseases and enable international transfer of germ plasm (Roca et al. 1979). At present, germ-plasm collections of cocoyams like many other tropical root crops are maintained in gene banks as field plants, as in-vivo conservation under more protected conditions would be very costly. This method of conservation tends to be expensive and is hazardous because of the vulnerability of the clones to pathogens and natural disasters. Our work was carried out to devise in-vitro methods for the conservation and multiplication of cocoyam.



Development of a protocorm piece in agitated B5 medium with 3% sucrose. The photograph was taken after 6 weeks in culture.

Materials and Methods

Two clones of *Xanthosoma sagittifolium* (IITA Green and IITA Red) and seed material were obtained from the International Institute of Tropical Agriculture, Nigeria, and B'ham variety was bought from Birmingham, England, market. This last clone is believed to be of tropical American origin. The clone IITA Green was included in all experiments.

The various genotypes were maintained as plants in a greenhouse with a minimum temperature of 25°C under 16 h daylight. These served as controls for comparisons with plants generated in vitro. All three types of buds on the corm, which are apical, axillary, and adventitious, were used, as were the buds "eyes" on the tubers. The bud types were all derived from one mature plant (IITA Green) grown in the greenhouse.

For culture initiation, axillary buds were excised, together with a piece of adjacent corm tissue (ca 2 cm^3) and the outer bud scales cleaned in flowing tap water. The buds were sterilized for 15 minutes in sodium hypochlorite solution (available chlorine 0.6% w/v) to which a few drops of Tween 80 were added as a wetting agent; they were then washed in sterile, double-distilled water, trimmed further, and submerged in sodium hypochlorite solution (0.3% available chlorine) for 5–7 minutes. After two rinses in sterile, distilled water, the buds were again trimmed before the shoot-tip explants (0.3–0.5 mm long), retaining one or two leaf primordia, were dissected on a petri dish under a binocular microscope and transferred to the culture medium, the cut surfaces being in contact with the medium. Shoot-tip explants (0.3–0.5 mm) of

[1] Department of Botany, University of Ghana, Legon, Accra, Ghana.

[2] School of Biological Sciences, University of Bath, Bath, England.

each of the cocoyam clones were derived from axillary buds of individual plants that had been growing in the greenhouse for 1 year.

Initiation and multiplication cultures were grown in 100-mL Erlenmeyer flasks containing 25 mL B5 medium (Gamborg et al. 1968) with 3% sucrose. The flasks were stoppered with nonabsorbent cotton wool and then covered with aluminum foil. The medium was sterilized for 15 minutes at 121°C and incubated at 16 h in daylight conditions (PAR 44 μmol/m²/sec) under continuous agitation at 65 rpm.

As initial experiments involving several basal media and hormones had indicated that B5 medium with a combination of 5×10^{-8} M NAA (naphthalene acetic acid) and 5×10^{-6} M BA (6-benzyl-aminopurine) was a suitable initiation medium, we used this medium, agitated continuously, with explants from four cocoyam genotypes (IITA Green, IITA Red, seed material, and B'ham variety).

Protocorms, spherical bodies that remained loosely attached to form clusters, formed in the initiation medium were allowed to grow on a hormone-free B5 medium for 6 weeks before use in further experiments. Pieces, 5–7 mm long, of protocorm clusters that had not formed organs were transferred to media containing factorial combinations of NAA (5×10^{-8} M and 5×10^{-7} M) with BA (5×10^{-7} M and 5×10^{-6} M).

Because of the high cost of storage at low temperatures in the tropics, culture conditions for long-term storage at temperatures close to ambient were investigated. Corm-piece explants (5 mm long) of IITA Green plantlets, which had been initiated and maintained on hormone-free medium, were inoculated onto 50 mL of various standard media with 1% sucrose (w/v), but without growth regulators.

"Corm-piece" explants (corm tissue with attached bud, 5 mm long) used in conservation experiments were derived from in-vitro cultures that had been initiated and maintained on hormone-free B5 liquid medium. The cultures were grown in 250-mL glass jars containing 50-mL B5 liquid medium supported on a filter paper bridge (Whatman 3 mm) held in place by two small glass vials. The cultures were incubated at 25°C under 16 h daylight conditions (PAR 63 μmol/m²/second). The storage cultures were observed at 4-week intervals and assessed as:

- Quiescent: cultures with no visible growths;
- Surviving: cultures with a green organ part;
- Degenerating: fully grown plantlets with deteriorating apical buds; or
- Healthy: regenerated plantlets with no visible sign of deterioration, capable of extended culture without subculture.

Results

In the agitated initiation medium (B5 medium with 3% sucrose and 5×10^{-8} M NAA and 5×10^{-6} M BA), the shoot-tip explants swelled to form a sphere of tissue from which small protrusions appeared. These grew progressively and developed into protocorms. On transfer to agitated medium with or without growth regulators, more spherical bodies formed; if transferred to stationary medium, they developed plantlets.

Within 18 weeks of culture, a high proportion of the explants from all the clones formed protocorms and plantlets in the initiation medium, although the actual amounts of protocorms in some cultures were small (Table 1). No marked differences were observed in the development of the different clones. The number of leaves/culture ranged from 6.1 for IITA Green to 11.5 for seed. The differences in numbers of cultures that formed protocorms and, hence, shoots and leaves indicate variations in the performance of the individual clones.

At 18 weeks, explants of all the bud types had developed protocorms, with subsequent plantlet

Table 1. Development of shoot tips from in-vivo clones in agitated medium at 24°C, 16 h daylight conditions (PAR 10 μmol/m²/second), after 18 weeks.

Cultivar	% Developing explant	% Plantlet regeneration	% Protocorm formation	Shoots/ culture	Leaves/ culture	Replicates
IITA Green	100	90	70	1.0	6.1	10
IITA Red	89	89	67	1.3	7.9	9
IITA Red	100	100	89	1.5	8.0	9
Seed	100	86	100	2.9	11.5	7
B'ham	100	100	86	1.0	6.5	8

regeneration ranging from 60% to 86% (Table 2). Axillary-bud cultures formed larger protocorms than did the other bud types.

On transfer of protocorm pieces (5–7 mm long) to the initiation medium, mean protocorm growth as determined by weight was 653% and 2607% at 4 weeks and 8 weeks respectively. As each protocorm piece contained about five protocorms, each of which was capable of producing one or more plantlet, at least 33 plants were produced from each piece within 4 weeks.

Corm-piece cultures on all the various media formed normal plantlets within 6 weeks, but all the cultures were degenerating at 52 weeks (Table 3). On transfer to normal growth conditions (B5 medium with 2% sucrose), cultures from Heller's (1953) medium formed multiple shoots derived from axillary buds and from new protocorms, which is a characteristic usually associated with aging cultures. Corm pieces on White's (1954) medium developed into large plantlets, but new leaves were progressively smaller after prolonged culture. The plantlets became smaller with well-developed corms. There was 100% survival, and all sprouted cultures (88%) were healthy with no sign of degeneration at 52 weeks. The results of another experiment involving the B'ham clone, grown on various media with 2% sucrose and incubated at 29°C, were similar in that only cultures on White's medium remained healthy at 52 weeks. These were incubated further, and at 80 weeks there was 100% survival (5 replicates). On transfer to normal growth conditions (B5 medium with 2% sucrose), all the axillary buds on the corms developed within 1 week; many of these developed into shoots at 6 weeks (6 shoots/culture), giving rise to nonadventitious multiple-shoot cultures.

Table 2. Development of different types of buds in agitated medium at 24°C, 16 h daylight conditions (PAR 10 μmol/m²/second).

	Explant type		
	Apical	Axillary	Adventitious
% developing buds	100	86	100
% plantlet regeneration	67	86	60
% protocorm formation	83	43	100
Leaves/culture	4.7	5.7	8.4
% shoot formation	100	86	60
Replicates	6	7	5

Culture derived from 80-week-old explant; picture was taken 4 weeks after transfer to B5 medium with 2% sucrose.

The mature plants derived from in-vitro cultures retained the general morphological characteristics of the cultivars grown in the greenhouse from cormels. The colour and shape of the leaves and the tubers obtained appeared to be normal. Somatic chromosome counts of root tips of the plants did not reveal any polyploids.

Discussion

The successful establishment of cultures from the clones in the initiation medium indicates that the method has wide applicability. Apical, axillary, and adventitious buds can all be used for culture initiation.

Cultures can be multiplied by several methods including regular subdivision of corms with axillary buds onto hormone-free B5 medium (Acheampong 1982). Protocorms produced in

Table 3. Survival of cultures from corm pieces of IITA Green on various media for 52 weeks at 25°C, in 16 h daylight conditions (PAR 63 μmol/m²/second).

Medium	% quiescent cultures	% plantlet formation	% survival	% healthy cultures
B5	12	88	0	0
B5, half strength	10	90	0	0
MS	20	80	50	20
MS, half strength	0	100	90	0
Heller's	0	100	100	0
Nitsch's	0	100	67	11
White's	12	88	100	88

agitated cultures can be multiplied either in hormone-free medium or in the initiation medium to produce, theoretically, more than 1 million plants a year.

For in-vitro storage of cocoyam germ plasm to be used as an alternative to field collections, the selected culture must ensure maximum genetic stability under pathogen-free conditions, and, ideally, the subculture interval should be extended to at least 1 year to reduce maintenance costs. The results of earlier work (Acheampong 1982) indicate that cocoyam cultures can be stored for at least 1 year under various minimal growth conditions without the loss of morphogenetic potential. The work reported here indicates that the cultures can be stored for more than 1 year (80 weeks in this case) without growth hormones on White's medium at ambient conditions.

This investigation was not concerned with plant-health problems, but other reports (Hartman 1974; Jackson et al. 1977) indicate that the in-vitro culture system could be used for the elimination and exclusion of diseases from cocoyam and taro stocks. Once pathogen-free cultures have been produced, standard aseptic procedures should prevent infection of stored material. Such cultures can facilitate the utilization of germ plasm by providing a system for the international distribution of material for breeding programs (Roca et al. 1979). With breeding and selection work, very often a rapid multiplication procedure is required to carry out trials. Once superior genotypes have been identified, there would be a need for rapid multiplication of good clean seeds for distribution to growers, possibly through protocorm formation.

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PRODUCTION OF HYBRID *XANTHOSOMA SAGITTIFOLIUM* AND TEST FOR RESISTANCE TO *PYTHIUM MYRIOTYLUM*

A. AGUEGUIA[1] AND S. NZIETCHUENG[2]

Macabo or new cocoyam (*Xanthosoma sagittifolium*) can be reproduced asexually in Cameroon because of the application of flowering-induction techniques and artificial pollination. The Institute of Agricultural Research (Njombé) has developed conditions that are suitable for seed germination and later growth of the plantlets, and these conditions are currently being used in the large-scale production of hybrids. Preliminary tests on hybrid clone resistance to *Pythium myriotylum*-induced root rot yielded inconclusive results. Research is being pursued in this area.

Macabo or new cocoyam (*Xanthosoma* sp.), of the family Araceae, is a native of tropical America. It was first cultivated in pre-Columbian times (Thompson and de Wet 1983), was introduced into West Africa around the 1840s (Wright 1930; Coursey 1968b; Plucknett 1970; Karikari 1971) and into Cameroon about the same time.

Macabo is a herbaceous monocotyledon with a stem that grows to about 1–2 m. Shiny dark green sagittate or hastate leaves spread from a large petiole. The underground portion consists of a rhizome and, at times, secondary corms or cormels. *Xanthosoma* sp. is propagated vegetatively. Flowering is rare (Wilson 1979), but, when it occurs, the inflorescence consists of a spadix of flowers enclosed in a spathe. The pistillate (female) flowers are at the base, whereas the staminate (male) flowers are at the tip of the spadix but separated from the fertile female flowers by a few rows of sterile ones.

Haudricourt's classification in 1941, which was based on Engler's work (1920), listed eight cultivated species, including *X. sagittifolium*, the species grown in West Africa (Onwueme 1978).

In Cameroon, *X. sagittifolium* is cultivated in the southern part of a region bounded on the north by the Adamaoua range. The plant has a preference for deep, well-drained soil in regions where rainfall exceeds 1000 mm. The corms and young leaves are the basic food for a large portion of Cameroon's population. From 1976 to 1981, the combined production of macabo and old cocoyam (*Colocasia* sp.) dropped from 1.8×10^6 to 7.76×10^5 t (Cameroon, Department of Agriculture, 1981). This decline, particularly in the production of macabo, has been caused largely by parasitic diseases, especially root rot attributed to *Pythium myriotylum* (Nzietchueng 1980a,b; 1983a,b, in press). The methods recommended for combatting this disease include improvement of cultural practices, use of fungicides, and the development of resistant varieties. These methods are currently being studied. The purpose of this paper is to discuss the results achieved in obtaining resistant varieties as part of the National Root Crop Improvement Program from 1979 to 1982. Results dealing with physical and chemical methods of control have been discussed elsewhere (Nzietchueng 1983a,b, in press) in this publication.

MATERIALS AND METHODS

There are three identified cultivars of *X. sagittifolium* in Cameroon, i.e., a cultivar with white flesh (highly susceptible to root rot), one with red flesh (exhibiting little susceptibility to the disease), and one with yellow flesh (highly resistant). To date, research to create hybrid varieties has concentrated on the white and red cultivars.

A number of authors (McDavid and Alamu 1976; Alamu and McDavid 1978a,b; Wilson 1979) have studied the use of artificial methods, i.e., induction of flowering by means of a gibberellic acid salt (GA3), to obtain macabo seed.

[1] Institute of Agricultural Research, Njombé, Cameroon.

[2] Institute of Agricultural Research, Dschang, Cameroon.

The compound was used at the Institute of Agricultural Research at Njombé (80 m altitude, volcanic soil, 1800–2500 mm rainfall) from 1979 to 1983 in local macabo cultivars.

From 1979 to 1982, corms from white and red cultivars were planted 15–30 March in ridges in a 20 m × 20 m plot (seed density = 6700 plants/ha, i.e., 10 ridges per cultivar). The material appeared to be clean.

Gibberellic acid (Pro-Gibb Plus, 10% GA3) was applied to the leaves when the plants reached the 4–6-leaf stage. The interval between the application and the emergence of the first flowers was recorded along with the number of flowers per plant and per cultivar. Pollination was carried out manually, the white cultivar as the female and the red as the male and vice versa. When flowers failed to develop, the peduncles were coated with N-6-benzylamino purine (BAP) dissolved in 1% lanolin. When artificial pollination succeeded, the spikes were collected. Maturity of the fruit was determined by a colour change from shiny green to pale yellow. The technique for removing the seeds has been described elsewhere (Nzietchueng 1979).

The media used for germinating the seeds or growing the plantlets in the nursery included soil extract plus 0.7 g agar (Prolabo)/L (control); rotted sawdust; 50% rotted sawdust plus 50% soil rich in organic matter; and peat moss. The different media were steam sterilized either in an autoclave (the agar medium) or with methyl bromide (Institute of Agricultural Research 1980). Following sterilization, the media were placed in crates, Petri dishes, yogurt containers, or jiffy pots.

The macabo seeds were surface-sterilized with sodium hypochlorite, titrating 10–11° on the chlorometric scale for 5 minutes, and washed three times in sterile distilled water. They were then dried between two pieces of filter paper and sown on the different media. Sprouting seeds were watered daily with water containing small concentrations of sodium hypochlorite. A 0.1% Mycostatin solution (Nystatin 1.0 × 10^6) was sprayed on the sprouting seeds to inhibit saprophytic fungal development.

The media were incubated in 25–30°C with 12 h of daylight. They were placed in plastic-covered cages to keep the relative humidity close to saturation.

Two hundred seeds were used for each treatment, which was replicated four times. The percentage of germinating seeds was recorded after 1, 2, and 3 weeks. The influence of the different media on the subsequent development of the plantlets was noted.

The method for testing resistance consisted of interspersing hybrid clones with the local infested cultivar or else planting the clones in soil assumed to be infested. Because of the large number of clones at the time of seed evaluation and the first clonal appraisal, the test method consisted of considering the soil the only inoculum. Beginning with the preliminary yield trials, both the soil and infested local white macabo plants, interspersed with the hybrid clones under appraisal, acted as the inoculum.

Results

Gibberellic acid (10% GA3) in concentrations of 1000 ppm/L of water induced flowering in macabo plants (Njombé ecological zone). Less satisfactory results were achieved with higher concentrations, i.e., 1500–2000 ppm, in the Nkolbisson ecological zone (centre–south, 700 m) (Institute of Agricultural Research 1980). The activity of exogenous growth regulators depends on environmental factors.

The first flowering occurred 60–90 days after application of GA3. Each of the treated plants produced at least one inflorescence. The average yield was 4–6 flowers/plant.

The production of pollen grains by one of the cultivars varies from year to year. Pollen grains have rarely been observed in the yellow cultivar. Seed from red × yellow or yellow × white crosses have not yet been obtained at Njombé. According to M.N. Alvarez (personal communication), the yellow cultivar is tetraploid (4n = 52), whereas the red and white cultivars are diploid (2n = 26). Further research is being done on crosses between the yellow and white or red cultivars (Institute of Agricultural Research 1982). BAP does not seem to have any effect on the rate of aborted inflorescences in different cultivars. When artificial pollination has proved successful, the spikes are collected 35–45 days later. Hundreds of thousands of macabo seeds have been produced over the past 4 years. Along with the control medium, the two media containing sawdust and the peat moss (Table 1) proved favourable to seed germination.

During the course of different experiments, seeds germinating in the mixture of rotted sawdust and rich soil produced the hardiest plantlets. This medium is best suited to the establishment of young plants in a prenursery. Soil rich in organic matter is best for the subsequent

Table 1. Influence of different media on seed germination and subsequent development of plantlets of *X. sagittifolium*.

Medium	% germination over time (in weeks)[a]			Influence of medium on plantlet development[b]
	1	2	3	
Soil + 0.7 g agar	60.2	75.0	90.2a	+
Rotted sawdust	30.0	60.0	70.0b	+
Rotted sawdust + rich soil	50.5	81.0	85.1a	+
Rich soil	40.0	55.0	70.0b	+ + +
Peat moss	50.0	65.0	85.0a	0

[a]Figures followed by different letters are significantly different at the 5% level.
[b]0 = no development; + = average development; + + + = very good development.

development of the plantlets (Nzietchueng 1980a,b). These two media are currently being used to produce hybrid plants in Cameroon.

The first seeds introduced at the Institute of Agricultural Research at Njombé in September 1979 were obtained from the International Institute of Tropical Agriculture (IITA, Nigeria). Some of the hybrid clones from this initial introduction seem to have a tolerance to root rot (Table 2). Hybrids from seed produced at Njombé from 1980 to 1982 are being subjected to either seed or clone evaluation. There is considerable variability in F_1 hybrids, which is related to plant hardiness and corm shape. The genus *Xanthosoma* has the potential for varietal improvement. At present, efforts are being concentrated on importing exotic material to broaden the genetic base of local material.

Table 2. Preliminary yields for hybrid clones undergoing evaluation, 1982.

Variety	Cormels/ plant	Cormels yield (t/ha)	Infection coefficient (root rot)[a]
80 005	4.7	3.1	0.6
80 048	5.4	4.27	0.0
80 071	5.5	2.00	0.6
80 073	3.2	1.9	1.0
80 074	1.9	0.1	4.0
80 079	4.7	1.5	1.5
80 080	1.3	0.2	3.0
80 087	2.8	1.1	2.0
White (local)	1.7	0.1	4.0

[a]A scale of 0–4 was used to grade infection: 0 = healthy plant; 1 = 25% infected; 2 = 50% infected; 3 = 75% infected; 4 = 100% infected.

Conclusions

The induction of flowering in plants from the family Araceae (*Xanthosoma* sp. and *Colocasia* sp.) with a gibberellic acid salt has already been reported in a number of countries, i.e., Florida, USA (Volin and Zettler 1976), Puerto Rico (Alamu and McDavid 1978a), Nigeria (Wilson 1979), and certain islands in the Pacific Ocean (Western Samoa) (Wilson and Cable 1983). The same applies to hybrid seed production (Volin and Zettler 1976; IITA 1979). These different techniques have been mastered and adapted to the ecological conditions prevailing in Cameroon (Institute of Agricultural Research 1979–82). In Nigeria, Wilson (1979) recorded the largest percentage of inflorescence when gibberellic acid was used in concentrations of 1500 ppm/L water. In Cameroon, the use of gibberellic acid in doses of 1000 ppm/L solution (Njombé ecological zone) and 1500–2000 ppm (Nkolbisson ecological zone) resulted in a high percentage of inflorescence.

Good seed germination and hybrid development were achieved with culture media made up of soil rich in organic matter alone or mixed with rotted sawdust in a ratio of 1 : 1.

The first tests that were conducted on the hybrid clones to determine resistance to *P. myriotylum*-induced root rot yielded inconclusive results. Because of the pleophagous behaviour of *Pythium* spp., it is often difficult to eradicate diseases caused by these organisms by creating resistant (tolerant) varieties. But successful cases have already been recorded (Adegbola and Hagedon 1970). The fight against root rot of macabo in Cameroon currently centres on research to obtain resistant hybrids (crossing the yellow and white or yellow and red varieties and using mutagenic substances.

GROWTH AND DEVELOPMENT OF *COLOCASIA* AND *XANTHOSOMA* SPP. UNDER UPLAND CONDITIONS

M.C. IGBOKWE[1]

Dry-matter accumulation by the different parts of cocoyams, *Xanthosoma sagittifolium* and *Colocasia esculenta*, was studied for 2 years (1980–81) under the upland conditions at Umudike, Nigeria. Sprouting started within 2 weeks after planting and was almost completed by 4 weeks. Leaf production, especially for *X. sagittifolium*, was slow in the first 6 weeks but, thereafter, increased rapidly, reaching a maximum at 16–20 weeks after planting. Leaf-area index was also maximum at this time. Cormel bulking was noticed as early as 8 weeks but became prominent at about 12 weeks. Maximal development of corms and cormels was achieved in *C. esculenta* at 22–26 weeks and in *X. sagittifolium* at about 26 weeks. At this period, leaf dry matter and leaf-area index were minimal, and cormel production accounted for 40–70% of the total tuber yield. Prolonging the duration of maximal foliation (to beyond 20 weeks after planting) would considerably increase the yield of Nigerian cocoyams.

Several workers have studied growth and development of yams (Sobulo 1972a; Njoku et al. 1973, Okezie et al. 1981); cassava (Enyi 1972b; CIAT 1980); potatoes (Ifenkwe and Allen 1978); and sweet potatoes (Scott 1950; Wilson and Lowe 1973; Enyi 1977b). Similar studies on cocoyams have been mainly limited to wetland or irrigated conditions such as in Hawaii where the crop could last for up to 15 months (Plucknett and de la Peña 1971). Sivan (1980) studied *Colocasia esculenta* in the upland conditions in Fiji where cocoyams grow for up to 12 months. Lyonga (1978) summarized cocoyam growth studies in Cameroon based on monthly samples taken from 3 months after planting at Dschang.

My work was intended as a supplement to Lyonga's work — a study of the accumulation of dry matter by the different parts of both *Xanthosoma* and *Colocasia* spp. under the upland conditions in Nigeria, where growth rarely continues after about 7 months.

MATERIALS AND METHODS

The study was undertaken for 2 years, 1980 and 1981, at Umudike. Cormels of Ede Ocha (*X. sagittifolium*) and Coco India in 1980 and Ede Ofe in 1981 (*C. esculenta*) were planted 60 cm apart on 1-m ridges in a randomized block design with six replications. Each subplot measured 3.6 m × 4 m and contained 24 stands. Four plants were sampled from the middle of a subplot in 1980 and six plants in 1981.

Sampling was done fortnightly (except for week 24 in 1981) beginning from 8 weeks after planting in 1980 and 4 weeks after planting in 1981 and continued to 26 weeks after planting. The plants were washed free of soil and separated into roots, corms, cormels, and leaves. Leaf area was determined by the core method (Watson and Watson 1953; Ifenkwe and Allen 1978). Dry-matter yields were obtained after oven-drying at 80°C to constant weight.

RESULTS AND DISCUSSION

Three major stages of growth were identified for cocoyams based on this study (Fig. 1). The first stage was from planting of the cormel to about 8 weeks later. Sprouting started after 2 weeks, reached 30–74% a week later, and was 76–91% at 4 weeks after planting. This stage was characterized mainly by emergence and growth of roots and leaves. Mean number of roots was 40 and 30 for *Colocasia* and *Xanthosoma* respectively, whereas mean root length was 27.4 and 17.9 cm. Growth, especially of the leaves, was slow — perhaps, as Onwueme (1978) suggested,

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

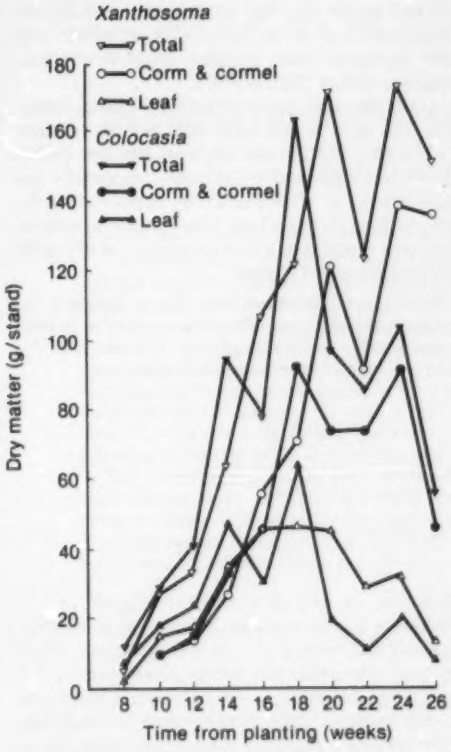

Fig. 1. *Dry-matter yields of* Xanthosoma *and* Colocasia *in 1980 in relation to time from planting.*

because growth was dependent on the nutrient reserves in the planted sett.

The second stage (about 8–24 weeks after planting) was marked by rapid production and growth of the leaves, which reached a maximum by 16–20 weeks (Fig. 2, Table 1); new corms (evident by 8 weeks and rapidly increasing after 10 weeks) developed very rapidly until 22–24 weeks (Fig. 2).

In other words, during this stage, the leaves, corms, and cormels were all developing rapidly. Sivan (1980) observed similar behaviour in Fiji and termed it "synchronous." The ratio of tops to corms (plus cormels) during this stage was 2 : 0.2.

The final stage lasted from 25 weeks to harvest and was characterized by a general senescence of the plant. The decline in leaf production started at about 20 weeks and the corms and cormels increased little after 24–26 weeks. Cormels detached and resown at this stage easily sprouted. Leaf-area index was very low (0.24–0.30) by this period (Table 1) and partly accounted for the low ratio (≤ 0.10) of tops/corms (plus cormels).

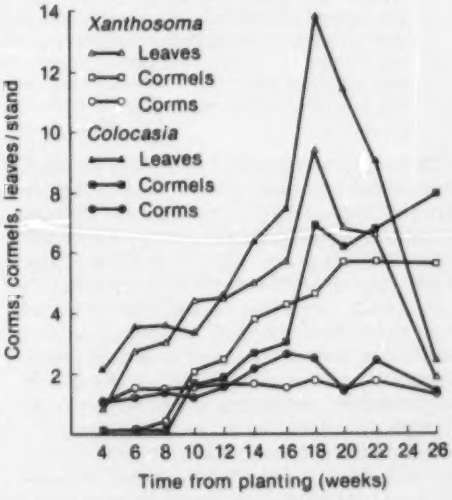

Fig. 2. *Number of corms, cormels, and leaves of cocoyams in relation to age, 1981.*

Table 1. Leaf area and leaf-area index of cocoyams in relation to planting time.

Weeks from planting (1980)	Leaf area (cm^2/stand)		Leaf-area index	
	Colocasia	*Xanthosoma*	*Colocasia*	*Xanthosoma*
8	1343.3	357.0	0.22	0.06
10	3170.7	2627.4	0.53	0.44
12	4313.6	3187.6	0.72	0.53
14	7619.2	4841.5	1.27	0.81
18	14267.1	9334.3	2.38	1.56
20	2898.0	6959.8	0.48	1.16
22	1624.6	4866.1	0.75	0.83
24	4526.4	4973.1	0.75	0.83
26	1775.4	1609.4	0.30	0.24

Cocoyam is similar to yam in that dry matter accumulates in the aerial parts (vines, leaves, and flowers) at a maximum about 16–20 weeks after planting (Okoli 1980). However, in some species of yams (*Dioscorea alata* and *D. esculenta*), storage-organ development occurs after maximal canopy production (10–13 weeks). Unamma (1981) showed that *D. rotundata* started to form tubers as early as 8 weeks, corresponding to the time corm bulking was observed in this study. Corm bulking proceeds as fast as leaf development and eventually supersedes leaf production. In yams, rapid tuber bulking starts after the attainment of maximal leaf area.

The rapid decline in leaf area after maximal foliation contrasted sharply with results for cocoyams under flooded or irrigated conditions (Plucknett and de la Peña 1971), in which leaf area increased from planting to 24 weeks and declined slowly (Sivan 1980).

Under the upland conditions in Nigeria, maximal leaf area is low and lasts not more than 2–3 weeks. This partly explains the low yields (5–7 t/ha) obtained by farmers, especially on acid-sand soils. Yields could be improved markedly by irrigation and soil amendment to ensure leaf area remains at a maximum for the whole of the second growth stage.

The Director, National Root Crops Research Institute, Umudike, granted me permission to publish this paper. The help rendered by O.B. Arene, J.C. Ogbonnaya, and C. Iruke was much appreciated.

EFFECTS OF WATER-TABLE DEPTH ON COCOYAM

B.S. GHUMAN AND R. LAL[1]

Physiological response of cocoyam (*Colocasia esculenta*) to different water tables was investigated in a lysimeter study during the dry season of 1981–82. Test cultivars were TCe 23 and TCe 36. Water tables were maintained at 15, 30, 50, and 70 cm below the soil surface. The control was without a water table, the plants being watered equal to an average pan evaporation on alternate days. The differences in water table did not affect stomatal resistance of the cultivars. In general, the stomatal resistance was minimal, about 3 seconds/cm, just after sunrise, increasing slowly to 6.5 seconds/cm just before sunset in all treatments. The average leaf-water potential at 1515 h increased from −6.6 to −5.1 bars in TCe 23 and from −6.4 to −4.0 bars in TCe 36 with the lowering of water table from 15 to 50 cm, and there was not appreciable change with further lowering of water table. In the controls, leaf-water potential was −3 bars in TCe 23 compared with −5 bars for TCe 36 at 1515 h. There was no direct relationship between stomatal resistance and air temperature, solar radiation, or relative humidity, but leaf-water potential of both cultivars decreased rapidly with increasing air temperature and solar radiation and decreasing humidity. Total water use was the highest, 68.8 cm in 89 days, in lysimeters that had a water table at 15 cm deep and the lowest, 14.9 cm, in lysimeters with a water table at 70 cm.

Physiologically, little is known about the response of cocoyam to environmental variables, e.g., thermal and moisture patterns of the soil, air temperature, incoming radiation, and atmospheric humidity. An understanding of these parameters could permit their optimal use in production and could facilitate breeding programs, as has been demonstrated for maize (Kilen and Andrew 1969), soybean (Sammons et al. 1978), and *Solanum* potato (Krug and Wiese 1972). Although little work has been done on cocoyam (Haynes et al. 1967), Caesar (1980) used leaf-diffusion resistance as a criterion to assess the level of water stress in cocoyam plants.

This paper presents observations of stomatal and leaf-water potential of cocoyam at different water-table depths. Effects of evapotranspiration rates and other environmental variables are also discussed.

MATERIALS AND METHODS

The experiment was conducted during the dry season of 1981–82 in field lysimeters constructed on the farm of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The mean annual rainfall is about 125 cm, of which less than 2% falls during the dry season (November–March). Metallic drums, 200 L each (58 cm diameter and 86 cm deep), were used as lysimeters. Bottoms intact, they were buried flush with the ground surface in two rows, 10 drums each. The distance between and within the rows was 100 cm and 50 cm, respectively.

Quartz gravel was poured into each drum to form a 5-cm thick layer and then covered with soil (bulk density of packing 1.4 g/cm^3). The soil, sandy loam in texture and containing about 2% organic carbon (Moormann et al. 1975), belongs to the Apomu series and is classified as Psammentic Ustorthent. In the centre of each drum, a rigid plastic pipe, 5 cm diameter, with 3-mm wide holes at 5-cm intervals along two opposite sides, was installed so that the water table could be regulated by a Mariotte bottle technique. The lysimeters, thus, could be drained through this central tube with a manually operated water pump.

Cormels with young suckers intact were cut from the old crop corms and used as a propagating material. The two cultivars tested were TCe 23 and TCe 36. One sucker of each cultivar was

[1] International Institute of Tropical Agriculture, Ibadan, Nigeria. Present address of B.S. Ghuman: Soil and Water Management Section, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.

planted per lysimeter on 16 November 1981. To each lysimeter, urea, single superphosphate, and muriate of potash were added at planting to supply NPK, 50 kg of each element/ha. Under optimal water and nutrient supply, both cultivars average 100–200 cm high, yielding 10–18 t/ha, and maturing in 6–9 months, although TCe 36 is relatively early maturing (M.N. Alvarez, personal communication).

There were four treatments in which the water table was maintained at 15, 30, 50, and 70 cm below the soil surface, and the control was a drum in which no water table was present and the plants were irrigated every other day with water equal to mean pan evaporation during the dry season, i.e., 4.5 mm/day (IITA 1979, 1980). The treatments, which were imposed on 15 December 1981 (29 days after planting) till 22 March 1982 (harvest), were replicated thrice in a randomized block design. The plants were harvested just before the onset of the rainy season owing to the difficulty in maintaining water tables.

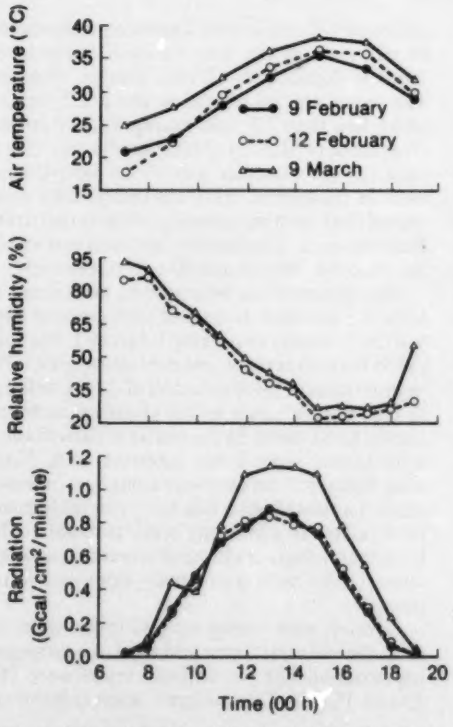

Fig. 1. *Solar radiation, relative humidity, and air temperature on 9 and 12 February and 9 March 1982.*

In the evening preceding measurement days, leaves were covered with perforated paper bags to keep dew from forming on them. Stomatal resistance was measured with a Lambda model LI 60 diffusion porometer (Kanemasu et al. 1969). A preliminary greenhouse experiment revealed that the stomata were predominantly present on the lower side of the leaf, and first, second, and third leaves from the top responded similarly to soil-moisture stress. The measurements reported here were made at one position on the lower side of the second leaf at 2-hour intervals throughout the day. The measurements at the existing leaf temperature were corrected to 25°C.

Leaf-water potential of the third leaf was measured with a pressure chamber (Scholander et al. 1965). A strip about 8–10 cm long along the secondary vein of the leaf was cut with a sharp razor blade and transferred quickly to the pressure chamber lined internally with moist filter paper; within 2–3 minutes the leaf portion around the secondary vein was stiffer than the portion between veins and gave concordant readings.

The air temperature was measured at 1 m above ground with a mercury-in-glass thermometer that was shaded from direct sunlight. The incoming radiation was measured from a pyrheliograph chart using a planimeter. The relative humidity was monitored by a hygrothermograph. The daily pan evaporation was measured by a class-A pan evaporimeter.

The water in the Mariotte bottles was replenished daily at 0830–0900 h, and the amount added was recorded — assumed to be equal to the water transpired by two plants plus that evaporated from the soil surface in the lysimeter. These records were used to calculate the evapotranspiration rate on a daily basis.

Results and Discussion

During the dry season in Nigeria, conditions throughout the day remain hazy because of a fine dust blowing from the Sahara desert. After sunrise at about 0700 h, the incoming radiation increases gradually till noon (to a per-minute peak of about 0.82 Gcal/cm^2 on 9 and 12 February and about 1.12 Gcal/cm^2 on 9 March). The peak incoming radiation was maintained till 1500 h and then gradually decreased to zero at about 1900 h (Fig. 1). The morning air temperature (18°, 21°, and 25°C) rose to 36°, 36°, and 38.5°C about 1500 h on 9 February, 12 February, and 9

March, respectively. On the latter 2 days of measurements, the relative humidity of the atmosphere was at a maximum, about 90%, in the morning, decreased to about 26% at 1500 h and increased again toward evening.

Predawn values for stomatal resistance of both cultivars were high, 24–59 seconds/cm, decreasing to a minimum, 2–4 seconds/cm, at 0845 h (Fig. 2). The stomatal resistance of TCe 23 increased suddenly to 10.5 and 30 seconds/cm in lysimeters with water tables at 15 and 50 cm, respectively, and 23 seconds/cm in the control at 1045 h on 9 February. An increase was also observed with the TCe 36 control. On other days, resistance increased slowly to an average of 6.5 seconds/cm about 1645 h irrespective of the cultivar and water table. However, stomatal resistance increased rapidly after sunset. Caesar (1980) also measured stomatal resistance values

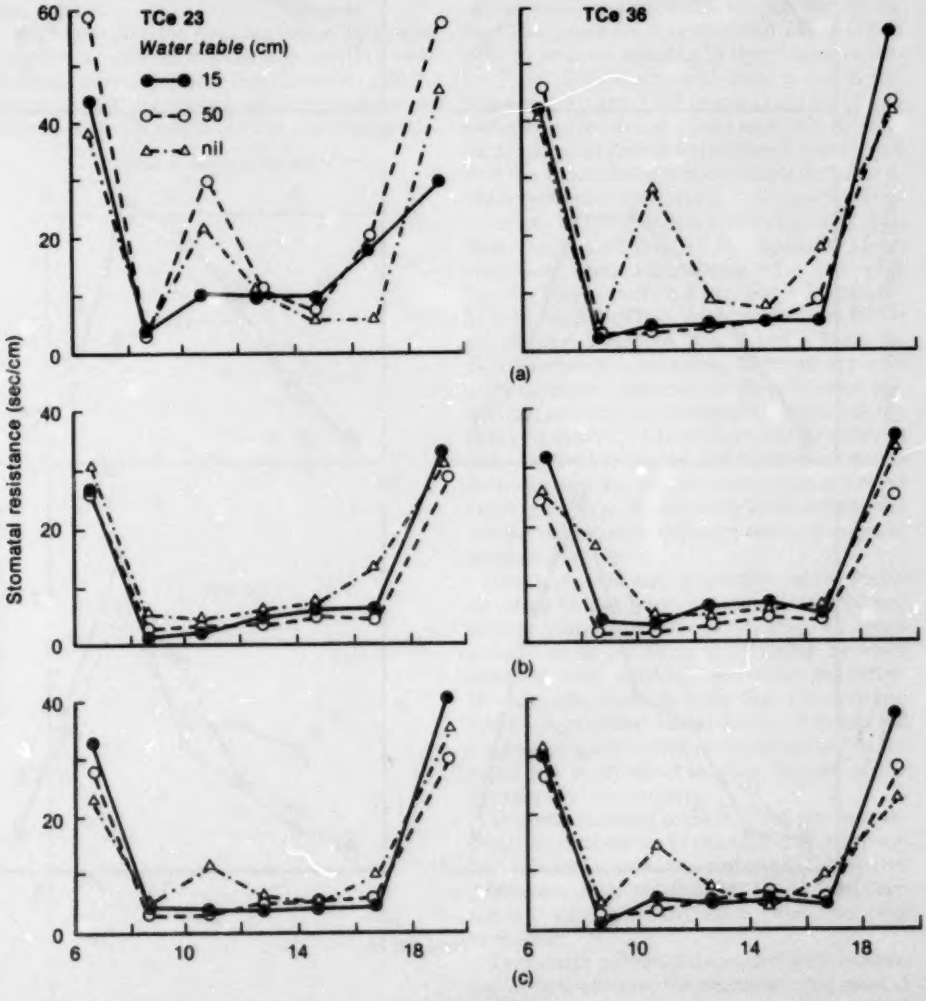

Fig. 2. *Stomatal resistance, on (a) 9 February, (b) 12 February, and (c) 9 March 1982, of TCe 23 and TCe 36 grown in lysimeters with two different water tables (15 and 50 cm) compared with the control plantings (no water table).*

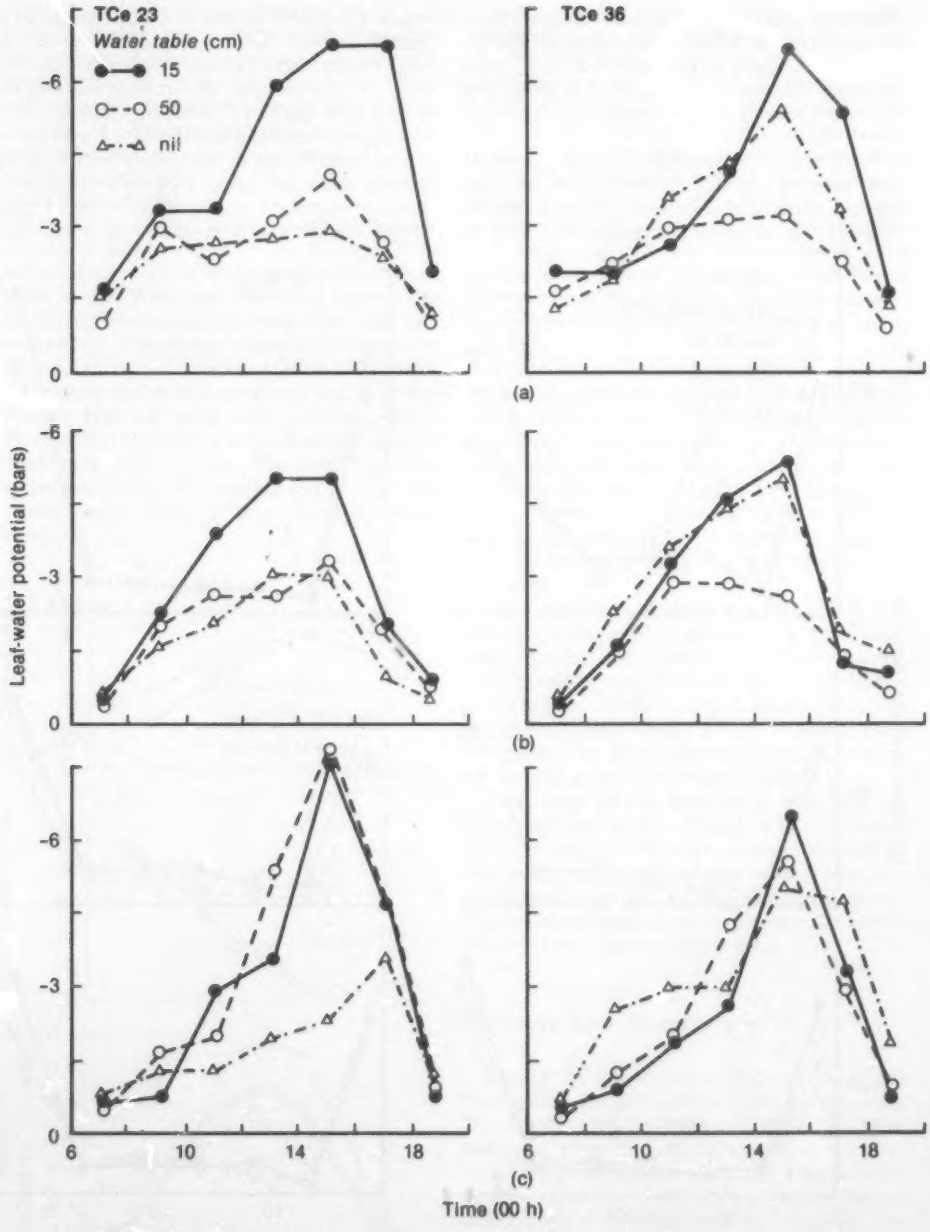

Fig. 3. *Leaf-water potential, on (a) 9 February, (b) 12 February, and (c) 9 March 1982, of TCe 23 and TCe 36 grown in lysimeters.*

of *C. esculenta* between 3.6 and 8.6 seconds/cm during daytime for irrigated and stressed treatments. Our values lie well within this range. However, our observations indicated relatively less variation in the daytime stomatal resistance (4–6 seconds/cm) over a range of soil-water contents (6–23% by weight at 5 cm deep depending on water table). Therefore, we suggest that leaf-diffusion resistance should be used with some caution as an indicator of soil-water and plant-water status.

On 9 February, the morning values of relative humidity as estimated from wet- and dry-bulb readings were incredibly low, 35–40%, which, coupled with increasing air temperature at 1045 h, probably increased the evaporative demand of the atmosphere. This change, in turn, probably brought about the closure of the stomata and resulted in high resistance values. After a few hours, when the plants were adjusted to the environment, the stomatal resistance would fall almost to the morning values. The plants in which the water table was maintained at 15 cm below the surface did not indicate stomatal closure, probably because of nonlimiting water supply.

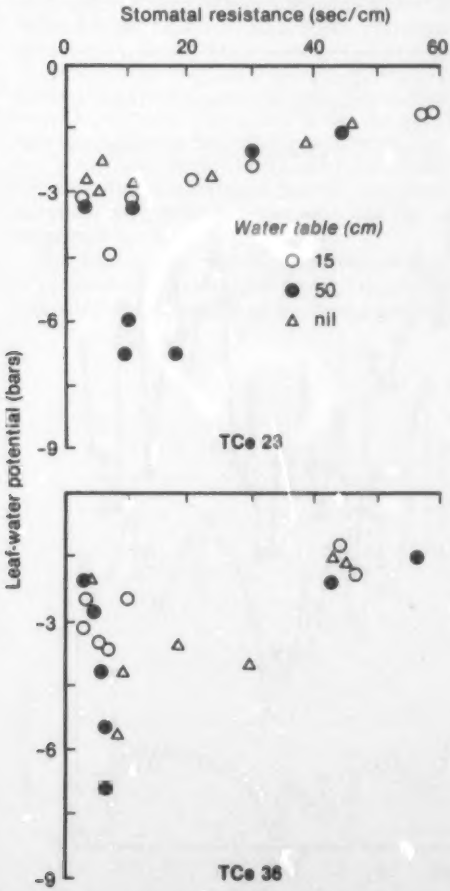

Fig. 4. *Leaf-water potential at different levels of stomatal resistance.*

Leaf-water potential fell rapidly during the day. The minimum was observed about 1515 h (Fig. 3) and was affected by water-table depth. On 9 and 12 February, leaf-water potential was between −5.1 and −6.8 bars at 1515 h for TCe 23 with the water table at 15 cm; with TCe 36, leaf-water potential ranged between −5.4 and −6.8 bars. At a water table of 50 cm below the surface, water potential was about −3 bars for both cultivars. In contrast, on 9 March, a day with high energy load (Fig. 1), the figures at 15-cm and 50-cm water tables were −7.8 and −8.2 bars for TCe 23 and −6.8 bars and −5.8 bars for TCe 36. In the control, water potential at 1515 h was about −3 bars for TCe 23 and −5 bars for TCe 36 cultivar, irrespective of the energy load and evaporative demand. At these minimal values, wilting of the leaves was not observed in any of the treatments. Recovery of leaf turgidity as indicated by the rise of leaf-water potential in both cultivars for all treatments began toward evening because of increasing relative humidity and decreasing solar radiation and ambient temperature (Fig. 1).

The high stomatal resistance values corresponding to high water potentials occurred just before sunrise and after sunset (Fig. 4). There seemed to be no direct relationship between stomatal resistance and leaf-water potential. However, the results indicate that, for cocoyam, leaf-water potential values up to −7.8 bars did not limit the leaf-diffusion resistance and hence could not bring about midday closure of the stomata of either cultivar.

Daytime stomatal resistance did not vary appreciably in response to changes in air temperature (17–38°C), relative humidity (22–95%), or per-minute solar radiation (0.3–1.12 Gcal/cm^2) for the days that diffusive resistance was monitored.

Leaf-water potential decreased with increasing air temperature, the decrease being most in the highest water table followed by the control and then the water table at 50 cm — relationships indicated by the slope of the respective regression equation (Table 1). Similarly, the leaf-

Table 1. Regression equations between leaf-water potential (− bars) and air temperature, AT (°C), relative humidity, RH (%), or solar radiation, SR (Gcal/cm²/min), for cocoyam cv. TCe 36.

Environmental variable	Treatment		
	WT_{15}	WT_{70}	WT_{no}
Air temperature	−3.76 + 0.22 AT r = 0.63	−2.02 + 0.14 AT r = 0.61	−2.96 + 0.19 AT r = 0.74
Relative humidity	0.28 − 0.05 RH r = −0.64	4.10 − 0.04 RH r = −0.55	5.31 − 0.04 RH r = −0.69
Solar radiation	1.23 + 3.46 SR r = 0.68	0.85 + 3.06 SR r = 0.89	1.49 + 3.18 SR r = 0.81

water potential decreased with increasing solar radiation and decreasing relative humidity. Leaf-water potential showed a hysteresis phenomenon, i.e., the values before minima (that occurred at 1515 h) were different from values after minima, in response to environmental variables. Water potential versus air temperature followed a clockwise direction and when plotted against the relative humidity and radiation levels followed a counterclockwise path. Further, the correlation coefficients (r) reveal that the solar radiation was the most important environmental variable influencing leaf-water potential, followed by ambient temperature and atmospheric humidity.

Evapotranspiration rate of cocoyam for

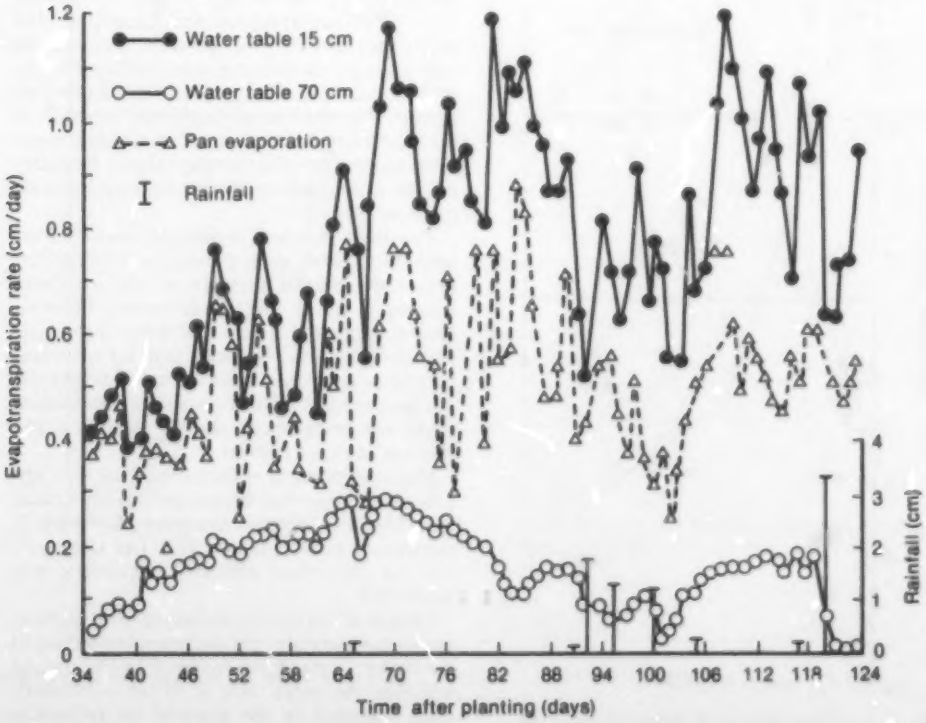

Fig. 5. *Comparison of evapotranspiration rates in lysimeters with water tables at 70 and 15 cm.*

89 days (21 December 1981–20 March 1982) from planting to harvest varied according to open pan evaporation (E_o) (Fig. 5). Following a rain, it abruptly declined; compared with E_o, it was always high in the treatment with the highest water table and low for the treatment with the lowest water table. The average evapotranspiration rates for the period were 0.77, 0.52, 0.34, and 0.17 cm/day for the four treatments (highest to lowest water table, respectively). The average potential evaporation rate was 0.51 cm/day. For summer in Japan, an evapotranspiration rate of 0.5–0.7 cm/day was reported for well-watered cocoyam (Kato et al. 1969). During 89 days of measurements, the treatments (highest to lowest water table) utilized 68.8, 46.0, 30.5, and 14.9 cm of water, respectively, in comparison with 45.3 cm measured by class-A pan evaporimeter. Leaf area per two plants at harvest for the corresponding treatments was 4122, 3373, 2642, and 1594 cm^2 respectively. The highest evapotranspiration was found in the treatment with the shallowest water table and the greatest leaf area. Kato et al. (1969) and Naito (1969) reported that transpiration rate of taro plants increased with increased leaf area and rise in temperature.

The weekly averages of evapotranspiration (ET) and potential evaporation (E_o) rates were computed and subjected to multiple regression analysis: $ET = 0.50 + 0.76\,E_o - 0.01\,WT$; $R = 0.92$ where ET and E_o are weekly means expressed in cm/day and WT (water table) in cm. The relation shows that weekly evapotranspiration rate is related positively to pan evaporation and negatively to water-table depth, and these variables (E_o and WT) accounted for 84% of the variation in the measurements of ET.

Conclusions

The stomatal resistance of the cultivars studied was not affected by the water-table treatments. The afternoon leaf-water potential of both cultivars increased with the lowering of the water table. In the control, leaf-water potential of TCe 23 was higher, −3 bars, than that of TCe 36, which was about −5 bars. Under conditions of this study, stomatal resistance did not show any relation to leaf-water potential and the environmental variables studied. However, leaf-water potential was influenced by the environmental parameters that affect evaporative demand.

We wish to thank Dr T.L. Lawson for permitting us to use pan-evaporation and relative humidity data and Dr M.N. Alvarez for supplying the planting material.

INTERCROPPING COCOYAMS WITH PLANTAIN: EFFECTS ON THE YIELD AND DISEASE OF COCOYAMS

M.C. IGBOKWE,[1] O.B. ARENE,[1] T.C. NDUBUIZU,[2] AND E.E. UMANA[3]

Cocoyams were intercropped with plantain at various populations at Ikom, Uyo, and Umudike in 1981. The cocoyams were tested at 10 000, 20 000, 30 000, and 40 000 stands/ha, and plantain populations were 800, 1600, 2400, and 3200 stands/ha. Averaged over all populations, *Xanthosoma sagittifolium* had decreased corm and cormel yields (24% less than sole crops) at all three locations. *Xanthosoma* yields decreased with increasing plantain populations. At Ikom, the reduction in yield was 46.6% at a population of 2400 stands/ha as against 11.6% at a population of 1600 stands/ha. In contrast, plantain populations had an insignificant effect on *Colocasia esculenta* yields probably because the profuse suckers produced by *Colocasia* suppressed plantain growth. Larger cocoyam yields were obtained at Ikom (basaltic soils) than at Umudike and Uyo (acid sands). *Sclerotium rolfsii* was observed at both Uyo and Ikom. Although it did not cause marked reductions in yield, it may have contributed to postharvest decay. At 1600 plants/ha for plantain and 20 000 plants/ha for *X. sagittifolium*, yields of the latter were highest and *S. rolfsii* prevalence was low.

The productivity of cocoyam intercropped with plantain has been documented by Devos and Wilson (1978) and Karikari (1981), and the combination is popular among West African farmers. The optimum populations of the two crops have not yet been determined; this was the focus of our study.

MATERIALS AND METHODS

Xanthosoma sagittifolium (cultivar Ede Ocha) and *Colocasia esculenta* (Ede Ofe) were planted in trials at Ikom and Uyo, Nigeria, May–June 1981. At Umudike, *X. sagittifolium* was planted in a similar trial. The cocoyams (60–90 g setts) were planted at four populations: 10 000, 20 000, 30 000, and 40 000 stands/ha corresponding to spacings of 1 m × 1 m, 1 m × 0.5 m, 1 m × 0.33 m, and 1 m × 0.25 m respectively. A local plantain variety, Okigwi, with sword-type suckers was interplanted with each cocoyam species at populations of 800, 1600, 2400, and 3200 stands/ha. The design for each of the five experiments at the three locations was a randomized complete block with three replications.

Each plot received basal fertilizer at 80 kg N, 60 kg P_2O_5, 90 kg K_2O, and 20 kg MgO/ha. Cocoyam sucker numbers and height were deter-

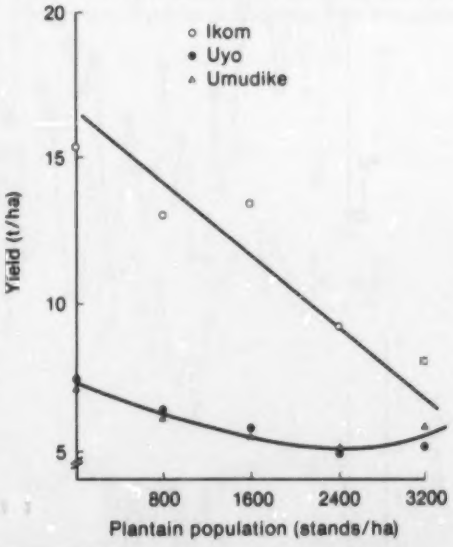

Fig. 1. *Yields of* Xanthosoma *at increasing plantain populations (LSD = 5.396).*

[1] National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

[2] Crop Science Department, University of Nigeria, Nsukka, Nigeria.

[3] Cross River Basin Development Authority, Calabar, Nigeria.

Table 1. Yields of corms and cormels from *Colocasia* sp. at various populations of plantain.

Plantain population (stands/ha)	Yield of *Colocasia* (t/ha)	
	Uyo	Ikom
0	6.15	11.73
800	7.27	12.96
1600	5.81	11.09
2400	5.43	11.78
3200	5.09	12.22

mined 5 months after planting from a sample area of 2 m^2 in each plot. Total yields were measured at harvest during the first week of March 1982.

Plantain bunches were harvested as they matured, but only the yields from the first flush were analyzed for this paper. Other measurements included number of plantain suckers and girth at 20 cm from ground level 5 months after planting. Cocoyams were attacked by *Sclerotium rolfsii*, and symptom severity was recorded on a scale of 1–5 where 1 was no symptoms.

Results and Discussion

Intercropping plantains with *Xanthosoma* decreased corm and cormel yields at all the locations, the decrease being significant ($P < 0.05$) at Ikom (Fig. 1). In contrast, the plantain decreased yields of *Colocasia* only an average 4% at Uyo and 1.6% at Ikom (Table 1), with no significant difference caused by increasing plantain populations.

Consistent with observations by Devos and Wilson (1978) and Karikari (1981), mean decrease of *Xanthosoma* yields was 24.2%, with values being 14.7%, 17.6%, 33.4%, and 31% at plantain populations of 800, 1600, 2400, and 3200 stands/ha, respectively. Thus, increasing the plantain population from 1600 to 2400 almost doubled the loss in yield of *Xanthosoma*.

These findings are not surprising because *Colocasia* grew more rapidly, and had more suckers, than *Xanthosoma*; both of these characteristics probably helped the *Colocasia* compete favourably with the plantains (Table 2), which did not grow well until the cocoyams were harvested (Table 2).

Table 2. Growth parameters of intercropped cocoyams and plantains.

Parameter	Uyo		Ikom	
	Colocasia	*Xanthosoma*	*Colocasia*	*Xanthosoma*
Cocoyam				
Suckers/2 m^2	455	55	334	20
Height (cm)	89	50	101	79
Plantain				
Suckers/plot	17	23	8	13
Girth (mm)	28	32	27	38

Table 3. Effects of density of cocoyams on yields (t/ha) of plantain–cocoyam intercrop[a]

	Cocoyam population/ha			
	10 000	20 000	30 000	40 000
Xanthosoma				
Umudike	4.13	6.18	6.75	6.85
Ikom	11.37	12.05	11.22	12.44
Uyo	4.62	5.83	7.21	5.85
Colocasia				
Ikom	11.03	12.92	11.40	12.53
Uyo	5.55	5.17	6.22	6.86

[a]Yields are means for all plantain populations.

Table 4. First bunch yields (t/ha) of plantains intercropped with cocoyams.

Cocoyam population	Plantain yields (t/ha)			
	Ikom		Uyo	
	Colocasia	*Xanthosoma*	*Colocasia*	*Xanthosoma*
0	3.24	2.09	0.46	0.47
10000	2.66	3.98	0.84	0.71
20000	1.86	3.56	0.52	0.58
30000	1.30	3.03	0.78	1.05
40000	2.72	3.06	0.31	1.06

At Umudike and Uyo, yields of *Xanthosoma* at 20 000 stands/ha were significantly larger than those at 10 000 but did not differ significantly from those at 30 000 or 40 000 stands/ha. This finding suggests that 20 000 plants/ha is adequate for intercropping with plantains in acid sands. At Ikom, where the soils are richer and are derived from basalt, a spacing of 1 m × 1 m (10 000 stands/ha) was suitable for both *Xanthosoma* and *Colocasia* (Table 3). The first yields of plantain were not significantly influenced by cocoyam populations (Table 4). Although these yields are only a fraction of the total plantain yields, they are an indicator of what to expect. Similar findings were reported by Devos and Wilson (1978), and Karikari (1981) recorded a 5% increase in the yield of plantains intercropped with cocoyams.

At both Uyo and Ikom, increases in plantain population decreased the prevalence of *S. rolfsii* in *X. sagittifolium*, whereas increases in the cocoyam population increased it. The lowest prevalence in both locations was noted with plantains at 1600 plants/ha and *Xanthosoma* at 20 000 plants/ha.

The severity of the disease symptoms was neither significant nor near the economic threshold, with scores ranging from 1.16 to 1.27 for *Colocasia* and 1.22 to 1.73 for *Xanthosoma*. However, the high prevalence of *S. rolfsii* probably contributed to postharvest decay.

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ROOT ROT OF *XANTHOSOMA SAGITTIFOLIUM* CAUSED BY *PYTHIUM MYRIOTYLUM* IN CAMEROON

SAMUEL NZIETCHUENG[1]

In Cameroon, root rot of macabo (or new cocoyam) (*Xanthosoma sagittifolium*) is a disease caused by *Pythium myriotylum*. It is widespread in the major areas of cultivation. Its development is directly related to certain environmental factors, such as heavy rainfall accompanied by high temperatures. The disease is transmitted primarily via infected seed (corms) and soil. High plant densities accelerate spread. Metalaxyl has proved effective against *P. myriotylum*, whereas Aliette has not.

Pythium myriotylum Drechsl has been cited as the pathogenic agent responsible for root decay in several graminaceous and leguminous plants (McCarter and Littrell 1968, 1970; Littrell and McCarter 1970; Ridings and Hatran 1976; Csinos 1979; Lipps 1980; Lipps and Bruell 1980; Minyogok 1981; Devay et al. 1982). The most characteristic symptoms are stunting and yellowing of the leaves (Csinos 1979; Nzietchueng 1980a,b; Devay et al. 1982). *Pythium* spp. organisms are major phytopathogenic agents, and a number of studies have been published dealing with identification and modes of dissemination as well as means of controlling these pests (Bell 1967; Gary and McCarter 1968; Adegbola and Hagedon 1969; Cox 1969; Frank 1968, 1972; Watanabe 1977). In general, heavy rainfall along with high temperatures and high plant densities promote the development of *Pythium* spp. diseases (Hendrix and Campbell 1973; Nzietchueng 1983a,b). In every instance, the disease is transmitted primarily via infected soil and seed. Fungicides have recently appeared on the market that have proved effective against *Pythium* spp. and *Phytophthora* spp. (Bakala and Trocme 1978; Bruck et al. 1980; Farih et al. 1981).

In this paper, I report the results of studies on macabo root rot in Cameroon that were carried out from 1979 to 1982 under the National Root Crop Improvement Program.

Disease symptoms on vegetative portions are stunting of the plant and yellowing of the leaves. In acute cases, the attack is brutal. The planted corms (seeds) are incapable of germinating or else germinate but fail to grow properly. This poor development of the plant is related to inadequate root formation, as the newly produced roots are destroyed by the parasite. The disease occurs as pockets of infection that gradually spread. These symptoms are characteristic of damping-off caused by soil-borne fungi.

In chronic forms, yellowing of the leaves is observed once the plants are firmly established (at roughly 3 months). This is by far the most common symptom. Yellowing begins by more or less regularly shaped spots on the edge of the lamina, which becomes chlorotic. The entire lamina then loses its colour, turns yellow, and shrivels up. As with the acute form, the disease occurs as pockets of infection that extend little by little.

According to Viennot-Bourgin (1964), organic disorders in herbaceous plants caused by soil-borne fungi generally develop when the plant is young. They may also occur when bulbs, tubers, and rhizomes begin to store reserves. In the case of the macabo, the onset of root rot coincides with cormel formation. As a result, infected macabo plants bear a number of cormels, but these are no larger than palm nuts.

Rot starts at the tip of the corms but lesions may occur anywhere on the root. The decayed tissue is initially dark brown but later turns black. When the infected root (soft rot) is pressed between the fingers, a central cylinder is found to be intact. This suggests that in the early stages of infection, the causal agent is a cortical endophyte that develops intercellularly. *Pythium myriotylum* is known to develop an in-

[1]Institute of Agricultural Research, Dschang, Cameroon.

Table 1. Influence of the amount of inoculum (*P. myriotylum*) on the development of the disease in the field in macabo planted on 8 April 1981 and artificially inoculated on 12 June 1981.[a]

Crushed mycelia/ 50 mL water	Observation dates (day/month)						
	26/06	09/07	23/07	07/08	21/08	08/09	17/09
200 cm^2	0.0	1.8	2.5	3.1	3.8	3.9	3.9
100 cm^2	0.0	1.0	2.0	2.8	3.0	3.1	3.2
50 cm^2	0.0	0.9	1.2	1.8	2.4	2.5	3.0
0	0.0	0.0	0.5	0.9	1.5	2.0	2.8

[a]Scoring system: 0 = healthy plant; 1 = 25% infected; 2 = 50% infected; 3 = 75% infected; 4 = 100% infected.

ter- and intracellular mycelium in the hypocotyl tissues of the bean *Phaseolus* sp. and secrete proteolytic and pectolytic enzymes (pectin-methylesterase) in culture media (Dow and Lumsden 1975; Nzietchueng 1983a,b, in press).

Artificial infection tests using either the local white macabo cultivar or F_1 hybrids (Nzietchueng 1979, 1980a,b) were conducted in greenhouses and in the field. They demonstrated that *P. myriotylum* was the causal agent (Steiner 1981; Nzietchueng, 1983a,b, in press) (Table 1). However, two other parasites, i.e., *Rhizocgonia solani* and *Fusarium solani*, are often found associated with this agent (Nzietchueng 1983a,b, in press).

History, Distribution, and Development

It is difficult to pinpoint when the disease first made its appearance in Cameroon. According to most authors, it was first observed in the 1970s (Nzietchueng 1980a,b; Minyogok 1981). In heavily cultivated areas, the disease, referred to as Appollo by the peasants, seems to have been present since 1969 (Minyogok 1981).

Macabo root rot is found predominantly in forest areas (Nyong et Kellé, Sanaga Maritime, Nkam, Mungo, Fako et Memé departments). These departments correspond to areas in which the mean temperature ranges from 22° to 27°C from June to October and the mean rainfall is approximately 1800 mm.

The minimum and maximum temperatures for mycelial growth of *P. myriotylum* are 10° and 45°C, respectively, with optimal temperatures in the 25–37°C range. Bell (1967) showed that *P. myriotylum* was particularly virulent in *Arachis* sp. at temperatures ranging from 18° to 35°C. In the forest areas of Cameroon where macabo root rot is prevalent, the temperature is between 18° and 34°C from July to October. In the high western plateaus where the disease is not a serious threat, the temperature for the same period ranges from 13° to 24°C. In the large macabo-growing areas of Cameroon, the pH of the soil is above 5.0. Only in the ferrallitic soils of the western region is the average pH under 5.0. *Pythium myriotylum* mycelium grows best at pH

Table 2. Development of root rot (planting date — 25–30 March).[a]

	15/06	30/06	15/07	30/07	15/08	30/08	15/09	30/09
1979								
% diseased plants	2.8	13.5	32.2	51.8	80.6	95.6	96.6	96.6
Infection index	0.1	0.4	1.2	2.0	3.2	3.9	3.9	3.9
1980								
% diseased plants	13.2	19.2	26.2	56.4	72.0	92.1	95.5	95.6
Infection index	0.4	0.8	1.0	2.2	2.9	3.7	3.9	3.9
1981								
% diseased plants[b]	—	45.0	70.0	80.0	93.8	93.8	93.8	96.0
Infection index	—	1.8	2.8	3.2	3.8	3.8	3.8	3.9

[a]Scoring system: 0 = healthy plant; 1 = 25% infected; 2 = 50% infected; 3 = 75% infected; 4 = 100% infected.
[b]Infected seed used.

Table 3. Influence of seed density on the development of disease and corm yields (planting date: 25 March 1981).

Seed density (plants/ha)	Diseased plants (%)	Infection index	Yield/ plant (kg)[a]	Yield (t/ha)
10000	92.7	3.7	0.95b	9.5
6700	92.5	3.7	1.30bc	8.6
4500	40.1	1.6	2.50a	11.1
3400	45.0	1.8	2.80a	9.3
2500	50.0	2.0	1.90c	5.0

[a]The figures followed by the same letter are not significantly different ($P < 0.05$).

Table 4. Influence of Metalaxyl and Aliette on root-rot development and cormel yields (end August 1981).[a]

Chemical	Amount (g)	Water (L)	Diseased plants (%)	Infection index	Yields (t/ha)[b]
Control	—		92.5	3.7	4.7a
Ridomil	20	10	10.0	0.4	5.6a
Ridomil	10	10	7.5	0.3	10.1b
Aliette	32	32	87.5	3.5	2.9a
Aliette	16	32	85.0	3.4	5.0a

[a]Seed density: 10 000 plants/ha.
[b]Figures followed by the same letter are not significantly different ($P < 0.05$).

6.0 and poorly at pH < 5.0 (Nzietchueng 1983a,b, in press).

In the macabo plant, the disease, like most *Pythium* spp.-induced diseases, spreads via infected soil and seeds. Experiments in 1979–80 using infected and clean seed and clean and infected soil revealed that plants from infected corms planted in infected soil developed poorly all throughout the growing cycle. When infected corms were planted in clean soil and healthy corms in infected soil, the resulting plants always developed the chronic form of the disease, i.e., yellowing of the leaves (Nzietchueng 1983a,b, in press).

Root rot spreads from area to area. In most instances, the infection begins in narrow, closed-in sites where drainage is poor. The disease spreads quickly, gaining 6–8 m a week. At the same time, secondary zones of infection form and fuse, which makes the rate of spread hard to assess.

The rot, which usually emerges in mid-June, is initially slow to develop; from mid-July to the end of August, it progresses rapidly (Table 2). Development can be divided into two phases. During the first, from mid-July to the end of August, the parasite spreads rapidly to new surfaces on the corms. The development of *P. myriotylum* is favoured by the mean temperature (26°C), relative humidity (89%), and rainfall (400–700 mm, July–September, Njombe ecological zone). The second phase extends from the end of August to mid-October and corresponds to the time when the surface area of the corm liable to infection is increasingly reduced. This is followed by a stabilization during which there is a combination of symptoms related to the disease and normal senescence of the plant (from mid-October to the end of December).

High plant densities favour the rapid spread of root decay. Trials conducted in 1980–82 provided evidence that, when the density was low, the disease was slow in its progression (Table 3). At the end of August, the prevalence of the disease was higher than 75% in plots with 6700 and 10 000 plants/ha and 50% or less in plots with less than 5000 plants/ha.

Chemical Control

Ten grams Metalaxyl/10 L water per plant led to rot control in macabo plants in 1981, whereas 20 g/plant proved phytotoxic. Concentrations of 10 g Ridomil per plant produced statistically better yields at harvest ($P < 0.05$). Similar results were recorded in 1982 (Table 4). Experiments with Ridomil in concentrations of 9 g/plant conducted in 1979 and 1980 were less con-

clusive than tests in 1981 in which the compound was used in concentrations of 10 g/10 L water/plant. The fact that Ridomil is effective only in high concentrations (applied by watering the soil with 10 g/m^2/plant) suggests that the substance undergoes biodegradation by soil-borne organisms or else largely leaches out.

Watering the soil with 1000 μg Ridomil/pot completely inhibits sporulation of *Phytophthora infestans*. Bakal and Trocme (1978) observed that Ridomil was ineffective in controlling brown rot in cocoa pods in Barong-Bikang (South West Province, Cameroon) because of the heavy rainfall. After application, the fungicide leaches out completely. This is also true in macabo corm rot in Njombe. Although macabo yields could be increased by 100% with Ridomil (Table 4), the cost of the fungicide prevents its widespread use. Aliette in concentrations of 32 and 16 g/plant proved ineffective in the control of the disease (Table 4).

SWEET-POTATO PRODUCTION POTENTIAL IN RWANDA

G. NDAMAGE[1]

Screening trials conducted under the ecological conditions prevailing in Rwanda enabled staff at Institut des sciences agronomiques du Rwanda (ISAR) to identify sweet-potato varieties for all ecological regions except the acid soils of the Zaire Crest–Nile highlands. Rusenya, Caroline lee, Nyiramujuna, and Rutambira clones have proved to be highly stable producers, but early, stable varieties that are adapted to the conditions existing at high altitudes have yet to be developed. Various planting techniques have been tested, and fertilization trials showed that two treatments, i.e., 0.02 t N, 0.05 t K_2O, and 35 t of manure; and 35 t of manure/ha alone, improved yields. In the dry regions, mulching produced spectacular results, increasing yields by 285%. The most beneficial effects were achieved with mixed stands of sweet potato–soybean–climbing bean–maize (land-equivalent ratio — LER = 1.53) and soybean–sweet potato–soybean–maize (LER = 1.60). Farm experiments on hillsides revealed that Rusenya, Caroline lee, Rutambira, and Nyiramujuna produced good results and that ridge cropping was adopted by the local farmers.

Sweet potatoes, together with beans, form the mainstay of the population's diet in Rwanda. Grown throughout the country up to altitudes of 2300 m, sweet potatoes generally produce well at elevations as high as 1900 m, but do poorly at higher elevations because of the cold. At an annual yield of 7.8×10^5 t, they represent 20% of the national food-crop production. Mean national yield is roughly 8 t/ha.

In rural areas, sweet potatoes are generally cultivated in fallow land. They are often grown in pure stands but are occasionally intercropped with beans, sorghum, or cassava. They are grown on the hillsides from September to May and in the lowlying and flooded marshlands from May to July. In marshlands, they are planted in large, raised ridges to facilitate drainage. When grown on the hillsides, they are generally planted in ridges or mounds.

The main factors limiting production are viral diseases transmitted mainly by lice (*Myzodes persicae*) and white flies (*Bemisia tabaci*); anthracnose, which is the most common fungal sweet-potato disease in Rwanda and is especially serious in the highlands; black weevils (*Cylas* spp.); leaf caterpillars (*Acraea acerata*); the cold, particularly at high altitudes; and drought in the western portion of the country.

[1] Institut des sciences agronomiques du Rwanda (ISAR), Butare, Rwanda.

RESEARCH RESULTS

In 1977, the germ-plasm collection at ISAR comprised 37 varieties, 9 of which, from IITA, were introduced for the first time. In trials since, Rusenya (17 t/ha) has proved to be the most stable clone and is well adapted to hillsides as well as marshlands. TIS 2544 (14 t/ha), which was introduced from IITA, is both a good and an early producer (4 months) but, like TIS 2534, has a high water content (35.5% dry matter) compared with Rusenya (37.5% dry matter). They have another drawback: at the plant densities common in Rwanda, these two clones grow poorly and cannot compete with or control weeds.

Along with screening operations, in 1979, ISAR began work to improve sweet-potato varieties by natural crosses. Some of the resulting clones are currently in the final stages of evaluation. Three varieties, Rusenya (17 t/ha after 6 months, highly versatile), Cordes Rouges (14.5 t/ha), and Nyiramajuna (14.5 t/ha), which were consistently high yielders at the research station as well as on farmers' plots, emerged from comparative tests conducted in several localities in 1979 and 1980.

In 1980, the five clones best adapted to high altitudes were Nsasagatebo (17.7 t/ha), Bukarasa (16.4 t/ha), Nyiranjyojyo (15 t/ha), Di Virosky 16 (14.8 t/ha), and Rusenya (14.2 t/ha). At medium altitudes, Rusenya (26.5 t/ha), 6634

Cordes Rouges (26.1 t/ha), and Nyiramujuna (23.5 t/ha) proved far superior to the other varieties. Nsenyakaniga (12.7 t/ha), Nyiramujuna (9.9 t/ha), and Gahungezi (9.6 t/ha) produced well at low altitudes. In all the ecological systems studied, the clone Nsasagatebo yielded moderately well.

Again in 1981, Rusenya was a good producer (mean 16 t/ha). An old clone, Anne Marie (17 t/ha), which is highly susceptible to viral diseases and cannot be distributed without a strict phytosanitary check in all the breeding plots, was the only clone that outyielded Rusenya.

In the northern region (Rwerere and Ruhengeri), Anne Marie and Nsulira 1026 produced 14.8 t/ha; Nyiramujuna 332, 12.3 t/ha; Rusenya, 12 t/ha; and Caroline lee 1668, 11.5 t/ha. At medium altitudes, Rusenya and Anne Marie came out in front with 23.5 t/ha, followed by Nyiramujuna 322 (21.3 t/ha), Cordes Vertes (20 t/ha), TIS 2544 (19.3 t/ha), Cordes Rouges (18,5 t/ha), and Nyiranjyojyo (18.3 t/ha).

In the dry region of Rwanda, the clones Caroline lee 1666 (21.8 t/ha), TIS 2544 (18.3 t/ha), Caroline lee (15.5 t/ha), and Nyiranjyojyo (15.5 t/ha) performed well.

In 1981, yields were highest at ETAB (25 t/ha), Rubona (18 t/ha), PNAP (13 t/ha), and Rwerere (14 t/ha).

Another series of clones were tested in 1982. The trials were begun late (mid-April) on the hillsides, and the acid soil of Mata proved early to be unsuitable for sweet potatoes if not previously cultivated. The average overall yield was low (9.1 t/ha), with the productive clones yielding only about 6 t/ha. The four best clones, in order of yield, were TIS 2498/16 (11.3 t/ha), Red Jersey 1220 (10.2 t/ha), Di Virosky 16/820 (10.0 t/ha), and TIS 2544 (10.4 t/ha). The best environments proved to be at Rwerere (19.6 t/ha), Rubona (11.7 t/ha), and Ruhengeri–PNAP (8.5 t/ha).

The clone Rusenya confirmed its yield potential under the conditions of the Rubona district (16.2 t/ha). It was followed by Anne Marie (14.5 t), which, however, was characterized by a thick cortex and stringy flesh. The new selections, Red Jersey 1220 (13.6 t/ha), Nsulira 1026 (13 t/ha), and Di Virosky 16/820 (12.8 t) rivaled the two local clones.

At high altitudes, the new varieties TIS 2498/16 (17.3 t/ha), TIS 2544 (16.6 t/ha), Di Virosky 16/820 (15 t/ha), and Red Jersey 1220 (14.2 t/ha) proved the most productive, whereas TIS 2498/16 (10.3 t/ha) headed the list in low-altitude regions, followed by Caroline lee (9.8 t/ha), Red Jersey 1220 (8 t/ha), and Caroline lee 1666 (7.7 t/ha). In other words, the new selection TIS 2498/16 produced good yields and exhibited considerable environmental adaptability.

In 1983 experiments grouped all the elite material in a single trial so that production stability could be assessed over a 4-season period. Some of the best clones were subjected to correlation analysis, which demonstrated the existence of a relationship between fresh tuber yields and dry tuber weight ($r = 0.66$), between vine weight and the percentage of dry tuber matter ($r = 0.50$), proper growth of the aerial portion contributing to dry-matter formation. Varieties producing large tubers also appeared to yield larger amounts of dry matter ($r = 0.55$).

Cultivation Techniques

Trials in which sweet potatoes were planted in ridges and mounds and on the flat were carried out during 1977–79, but no significant differences were recorded at the end of the trials.

Experiments on planting procedures and spacing were repeated over two seasons (1979). They showed that the interaction between the variety and plant density was not significant and that slightly better results were achieved with 50-cm than with 80-cm ridges. Likewise, results obtained with three stakes per hill did not differ from those achieved with only one stake per hill. There was no obvious advantage in planting presprouted roots instead of vine cuttings.

A trial with mineral and organic fertilizers conducted in 1982 in 15 localities selected in 10 agricultural regions with different soil types included 6 types of fertilizers and 5 sweet-potato clones, i.e., Rusenya, Caroline lee, and the three clones best adapted to each of the 10 trial localities.

Treatment with 20 kg N, 50 kg K_2O + 35 t manure/ha and with 35 t manure/ha alone proved beneficial in all the localities. Manure alone (35 t/ha) in the dry regions of Bugesera, Mayaga, and Mutara increased yields by 285% when combined with mulch (average yield 12.7 t/ha vs 3.3 t/ha without mulch). During the same trial, the varieties Rusenya and Caroline lee proved well-adapted to all the localities. Nyiranjyojyo gave good yields at low altitudes and Rutambira at high altitudes. Rusenya's mean surplus was 8.3 t/ha or 66% above control yields.

Mixed-crop trials, in which tubers were inter-

Tib I, a sweet-potato cultivar developed by IITA, is being grown for multiplication in Cameroon but has yet to prove itself in the conditions of Rwanda.

cropped with cereals and legumes, were carried out in a number of localities from 1979 to 1983. At medium altitudes, sweet-potato yields peaked when the tuber was grown as a monocrop. The highest energy per hectare was recorded when sweet potatoes were planted alone or mixed with maize (13.024 kcal and 14.215 kcal, respectively). Land productivity was the highest with pure sweet-potato stands, and when the intercrop was climbing beans. The highest density coefficients were recorded when sweet potatoes were intercropped with dwarf beans (170%), soybeans (169%), climbing beans (160%), and climbing beans plus maize (151%).

A mixed crop of maize–climbing beans–soybeans–sweet potatoes gave better results when one rather than two or three rows were planted with a single species.

Another mixed-crop system that continues to produce superior results (LER = 1.60) combines maize, soybeans, sweet potatoes, and soybeans with spacings of 1.80 m between the rows of maize. The sweet-potato ridges must be at least 50 cm high; otherwise, the plants are choked by adjacent rows of soybeans.

At present, preextension work or farm experimentation is carried out only in areas in the vicinity of ISAR stations but will soon spread to other localities selected for ecological conditions and soil types.

The best sweet-potato varieties (3 or 4) emerging from comparative varietal trials and the best cultural techniques (1 or 2) are used during farm trials. Each variety is planted both on ridges and on mounds so that a comparison can be made between the varieties as well as the two cultivation methods normally used in the rural areas. The block is roughly 16 m^2. Land preparation is done by the farmer who is joined by the researcher for staking, ridge and mound making, and planting. In general, manure is not applied. Maintenance consists only of manual hoeing, which is done on three occasions. Observations by research personnel are recorded from planting to harvest in the presence of the farmer. The crop is harvested 5 months after planting.

Current farm results indicate that yields are better when sweet potatoes are planted on

ridges rather than on mounds (16 t/ha vs 13.7 t/ha, respectively) and that this procedure represents a more efficient use of the land and labour.

Five of the best clones for the medium-altitude region were tested in 1980 in plots belonging to six farmers located throughout the region. The early variety Caroline lee (23 t/ha), Rusenya (14 t/ha), and Cordes Rouges (12.5 t/ha) demonstrated anew their production potential under farm conditions. Cordes Rouges received a good rating for its consistency, Rusenya for its taste, Rusenya and Nyirokayenzi for their shape, and Caroline lee for its colour (high carotene content).

Similar results were obtained in 1982 throughout the country where the varieties Rusenya and Caroline lee proved to be well adapted to the different localities. Nyiranjyojyo gave good yields at low altitudes and Rutambira at high.

COMPORTMENT STUDIES WITH SWEET POTATOES IN THE HIGHLAND ZONE OF CAMEROON

S.N. LYONGA[1] AND J.A. AYUK-TAKEM[2]

Comportment and stability studies were conducted with sweet potatoes on sites ranging in altitude from 1176 m to 1500 m in the wet and dry seasons. Palatability and ambient-storage tests were also carried out with these cultivars. In the first trial involving 11 Cameroonian and 3 exotic varieties, Pa 8 was identified as being high-yielding in the wet season and Pa 4 was the highest yielding cultivar in the August–January planting. Variety Pa 11 had good palatability (6.9 out of a total of 10.0) and ambient-storage (7.0 of 10.0) scores. In the second trial involving six sweet-potato cultivars, cultivar Tib 1 from the International Institute of Tropical Agriculture, Ibadan, was observed to be high-yielding in both the wet and the dry seasons, had a good taste score of 7.5/10.0, and had an average storage score of 5.5/10.0 at 45 days after harvest. Stability studies involving six cultivars grown from 1975 to 1978 were undertaken with Eberhart and Russell's (1966) regression method and Francis and Kannenberg's (1978) genotype-grouping technique. Variety Tib 1 was identified as being relatively stable in performance.

Sweet potatoes (*Ipomoea batatas*) are grown in most administrative provinces of Cameroon but are not a major staple crop. They are generally grown in association with other crops like cassava, maize, yams, beans, etc. In some localities such as in Bambili in Mezam Division of the North West Province, they are occasionally grown alone during the second season (August–January).

Annual production is low. In 1980–81, 2.96×10^5 t were produced, with a projected annual increase of about 9.2% (Cameroon, Government of 1976). The tubers and, in some parts of the country such as in the South Center Province, the young leaves are eaten.

Several varieties are grown in the country. The tubers range from round to cylindrical and are corrugated or smooth. The flesh colours include white, yellow, and red. The leaves also vary; some are serrated whereas others are ovate and pointed at the ends.

The objective of this study was to identify high-yielding and disease-tolerant varieties with good cooking qualities to be released for general cultivation in the highland areas where population pressure on the land is high (50–80 persons/km^2).

MATERIALS AND METHODS

The study was in two parts, namely:

- Collection and comportment study involving 14 different sweet-potato cultivars in three localities — Dschang (1500 m), Bambui Plain (1330 m), and Babungo (1176 m) — in the highland areas of Cameroon from 1968 to 1971; and
- Comparison of six sweet-potato varieties at Babungo from 1975 to 1978.

In both, the spacing was 1 m between ridges and 0.5 m between plants on the ridge (20 000 plants/ha). Plot size was 3 m × 12 m (3 ridges, 12 m long). All three ridges were used for data collection, and each plot received 54 kg of well-rotted farmyard manure (15 t/ha). Because of low temperatures at the three sites, tuber initiation was slow, and harvest was 5 months after planting (mid-March–mid-August — wet-season crops — and mid-August–mid-January — dry-season crops). Land preparation (mowing, plowing, harrowing, and ridging) was done with a Massey Ferguson 265 tractor.

The first part of the study was undertaken by Lyonga and Tardieu (1971) with 11 local and 3

[1] Root and Tuber Crops Programme, Institute of Agronomic Research, General Delegation for Scientific and Technical Research, Ekona, Buea, Cameroon.

[2] Cereals Improvement Programme, Institute of Agronomic Research, General Delegation for Scientific and Technical Research, Bambui, Bamenda, Cameroon.

Table 1. Mean tuber yields (t/ha), palatability, and storage scores of 14 sweet-potato cultivars grown at three highland sites in Cameroon from 1968 to 1971.

	Mean yield (t/ha)		Score (maximum 10.0)[c]	
	Wet season[a]	Dry season[b]	Taste	Storage (45 days)
Pa 1	13.5	4.5	6.5	4.0
Pa 2	11.0	2.9	5.3	3.0
Pa 4	11.2	5.8	5.0	1.0
Pa 6	9.1	1.2	5.8	2.0
Pa 7	16.7	5.0	5.0	3.0
Pa 8	21.8	4.3	5.5	1.0
Pa 9	6.1	3.0	8.2	3.0
Pa 10	7.8	2.2	7.5	2.0
Pa 11	13.5	3.3	6.9	7.0
Pa 12	6.5	1.3	5.9	4.0
Pa 13	9.1	3.0	6.9	6.0
Yellow flesh	5.5	3.4	4.6	1.0
TN 53	13.8	1.9	5.9	1.0
TN 57	13.3	4.0	4.6	8.0
LSD (P = 0.05)	3.7	1.1	0.9	1.9

[a]Yields are for three seasons (1968, 1970, and 1971).
[b]Yields are for two seasons, namely 1968 and 1970.
[c]Scores are for 1971 only.

exotic sweet-potato cultivars. The cultivars tested were Pa 1 and Pa 2 ex Dschang in the Western Province; Pa 4 ex Mbanga in Littoral Province; Pa 6 ex Manjo in Littoral Province; Pa 7, Pa 8, Pa 9, and Pa 10 ex N'Kolbisson in the South Center Province; Pa 11 ex Ebolowa in the South Center Province; Pa 12 (serrated leaves) and Pa 13 (ovate leaves) ex Bambili in the North West Province; Yellow flesh ex USA; and Tai Nang (TN) 53 and TN 57 ex Taiwan.

The comportment studies were carried out in 1968 at Dschang in the Western Province in both the wet and dry seasons. A similar trial was carried out at Bambui Plain in 1970; the first crop was weeded twice before being harvested, and the second was weeded only once. At Babungo, the cultivars were tested only in the March–August season, 1971. Trials were replicated eight times.

For the Babungo trial in 1971, the tubers of each variety were also assessed by a taste panel. The tubers were prepared for tasting in three different ways — namely boiled, roasted, and fried in groundnut oil. Before each taste, the panel washed their mouths with soda water. All scores were based on a scale of 1–10, with 10 being the best.

At Babungo, tubers of all the varieties were stored at ambient temperature for 45 days, after which they were scored (1–10). Again, a score of 10 was the best, indicating that the variety stored well.

The second part of the study (comparing performance of six varieties at Babungo) was con-

Table 2. Mean tuber yields (t/ha) of six sweet-potato cultivars grown at Babungo from 1975 to 1978.

	Yield (t/ha)					
	Wet season				Dry season	
	1975	1976	1977	1978	1975	1976
Tib 1	56.3	49.5	27.1	28.2	48.9	15.8
Tib 2	49.3	29.2	16.1	24.0	30.5	11.5
TN 53	43.7	15.1	15.5	21.0	46.8	1.8
Pa 7	36.5	26.1	12.3	21.1	30.3	6.2
Pa 8	31.4	33.4	19.9	26.5	39.2	4.9
Pa 11	26.9	17.2	11.3	18.0	25.4	3.6
LSD (P = 0.05)	12.9	14.5	6.5	4.4	11.2	6.2

Table 3. Taste and ambient-storage scores of six sweet-potato cultivars grown in the wet season of 1978 at Babungo.

	Score (maximum 10.0)				
	Taste				Ambient storage for 45 days
	Boiled	Roasted	Fried	Mean	
Tib 1	7.3	8.5	6.8	7.5	5.5
Tib 2	4.3	5.2	6.0	5.2	4.3
TN 53	4.0	6.0	5.3	5.1	2.0
Pa 7	5.5	5.8	4.8	5.4	2.5
Pa 8	6.0	5.2	5.7	5.6	1.3
Pa 11	7.3	7.0	6.6	7.0	7.6
LSD (P = 0.05)	1.5	1.3	0.8	1.1	2.5

Table 4. Regression coefficient, residual mean square, and mean tuber yield (t/ha) of six sweet-potato cultivars grown at Babungo from 1975 to 1978 during the wet season.

Cultivar	Regression coefficient	Residual mean square	Mean tuber yield (t/ha)
Tib 1	0.98 ± 0.03	0.00	40.3
Tib 2	1.40 ± 0.52	26.80*	20.7
TN 53	1.17 ± 0.63	15.50*	23.8
Pa 7	1.00 ± 0.26	13.50*	24.0
Pa 8	0.47 ± 0.11	1.99	27.8
Pa 11	0.62 ± 0.15	5.00*	18.4

*Significant at the 1% probability level.

ducted in the Ndop Plain from 1975 to 1978. Two crops were planted in 1975 and 1976, but from 1977 to 1978 only one crop was planted in the main rainy season (mid-March–mid-August). Each plot was replicated four times.

The trials comprised Tib 1 and Tib 2 from IITA, Ibadan, Nigeria; TN 53 from Taiwan; Pa 7 and Pa 8 from N'Kolbisson, Yaounde; and Pa 11 from Ebolowa.

In the 1978 first-season trial, along with tuber yields, palatability and storage at ambient conditions were assessed.

Eberhart and Russell's (1966) regression method was applied to tuber yields for the 4 years during the main growing season (mid-March–mid-August) as a measure of stability of performance of each variety. Eberhart and Russell (1966) defined a stable variety as one with a high mean yield, unit regression coefficient, and deviations from regressions as small as possible.

The method of Francis and Kannenberg (1978) was also used to determine stable varieties; this is the genotype-grouping technique. It plots the mean yield of each variety against the coefficient of variability (CV) of its yields over environments. The method groups varieties into four classes, namely high and low mean yields with small and large variations. Varieties with high mean yields with small variations are considered stable, with high performance.

Results and Discussion

In wet-season trials, cultivar Pa 8 significantly ($P < 0.05$) outyielded the other cultivars, and Yellow flesh yields were consistently inferior to the others tested (Table 1).

During the dry-season trials, Pa 4 significantly ($P < 0.05$) outyielded all varieties except Pa 7. Variety Pa 8, which outyielded other varieties in the wet season, ranked fourth in the dry-season trials. The wet-season yields (11.4 t/ha) were significantly higher than those for the dry season (3.3 t/ha) (Table 1), and, in general, most sweet-potato growers plant in March, taking advantage of the higher yields possible. The yields of the August–January crop are low because the rains usually stop before 15 November. If weather conditions are drastic, the sweet-potato weevils (*Cylas formicaris*) damage the tubers and are responsible for further yield reductions.

Cultivar Pa 9 had the highest taste score (8.2) but also had a low storage score (3.0). At the same time, this variety had low tuber yields in both wet- and dry-season plantings. Variety Pa 11, although lower yielding than Pa 8, had good taste (6.9) and storage (7.0) scores. Pa 13 had good taste and storage scores (6.0) but produced low yields. Among the exotic varieties tested, TN 57 had an average taste score (4.6) and a high storage score (8.0).

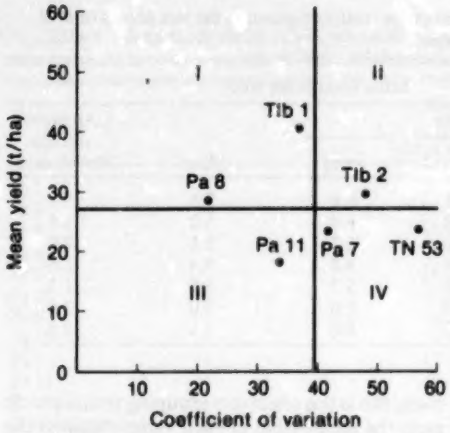

Fig. 1. *Mean tuber yields plotted against the coefficient of variation for six sweet-potato cultivars at Babungo: top left quadrant, high mean yield, small variation; top right, high mean yield, large variation; bottom left, low mean yield, small variation; and bottom right, low mean yield, large variation.*

During storage, soft and dry rot and sweet-potato weevils were observed, and their prevalence was high in cultivars that had a storage score of ≤ 3.0.

There was a lot of variation in tuber yields during the 4 years that the six sweet-potato cultivars were tested. Cultivar Tib 1 significantly ($P < 0.05$) outyielded (40.3 t/ha) all the tested cultivars except Tib 2 (29.7 t/ha) during the wet season. It also significantly ($P < 0.05$) outyielded Tib 2, Pa 7, Pa 8, and Pa 11 in the dry season (Table 2).

Cultivar Tib 1 had good taste (7.5/10.00) and fair storage qualities (5.5/10.0). Pa 11 had better storability (7.6/10.0) (Table 3), and this trait, perhaps, could be combined with the high-yield potential of Tib 1 through half-sib family selection.

Analysis of variance for yield stability revealed highly significant differences between varieties and between years. The differences between years reflected variations in rainfall and temperature but could not be attributed to soil type because the soil is fairly homogeneous (clay loam to silty-clay loam), with a pH of 6.0. The treatment × years interaction was also highly significant, indicating intervarietal differences in the pattern of response to yearly differences. Treatments with regression coefficients equal to unity (1) and residual mean square equal to zero (Table 4) were regarded as being stable. Thus, Tib 1 was the only cultivar considered stable, whereas, on the basis of Francis and Kannenberg's (1978) method (Fig. 1), cultivars Tib 1 and Pa 8 were both classified as stable.

EFFECTS OF VESICULAR–ARBUSCULAR MYCORRHIZAE, TEMPERATURE, AND PHOSPHORUS ON *FUSARIUM* WILT OF SWEET POTATO

J.M. NGEVE[1] AND R.W. RONCADORI[2]

Three sweet-potato cultivars were inoculated with *Fusarium oxysporum* f. sp. *batatas* (FOB) alone, vesicular–arbuscular mycorrhizae (VAM) fungi alone, or a combination of the two and grown at two temperatures and in soil with different levels of phosphorus. At 32°C, *Fusarium* wilt prevalence and severity were highest when plants were inoculated with FOB alone but, at 21°C, were highest when plants were inoculated with FOB and VAM jointly. Wilt prevalence and severity increased with increasing P fertilization, and VAM conferred protection to plants at low-P fertility (5 : 10 : 15 N, P, and K, ppm/g soil being 10, 4.4, and 8.3, respectively). This is the first report of the interaction of VAM fungi, P fertility, and temperature on *Fusarium* wilt of sweet potato. The role of VAM fungi in protecting plants against wilt and possible explanations for the observed results are discussed.

Much is now known about the etiology, epidemiology, and control of *Fusarium* wilt. However, little is known about how environmental factors affect disease development. This study was conducted, therefore, to determine the combined and separate effects of ambient temperature, soil phosphorus, and vesicular–arbuscular mycorrhizae (VAM) on incidence and severity of *Fusarium* wilt.

MATERIALS AND METHODS

We used three sweet-potato cultivars — W160, Centennial, and Sunnyside — that were obtained from the Southern Region Vegetable Laboratory, at Charleston, South Carolina, USA, and rated, respectively, as highly resistant, moderately resistant, and highly susceptible to *Fusarium* wilt.

The cultivars were grown in a mix of loamy soil and sand (1 : 1, v/v) and fertilized every 21 days with a 10–4.4–8.3 NPK fertilizer at a rate of 400 μg/g soil. Tip cuttings, 15–20 cm long, were taken from each cultivar and used in the experiments. All but four or five fully expanded leaves were removed, and succulent as well as woody cuttings were discarded.

A mix of shredded and screened Dothan loamy sand, washed river sand, and vermiculite (4 : 1 : 1, v/v/v) was used. Raw soil was analyzed by the Soil Testing and Plant Analysis Laboratory, University of Georgia, USA, and the results indicated pH 5.2, NO_3-N 9 μg/g, P 3.5 μg/g, K 50 μg/g, Ca 599 μg/g, Mg 119 μg/g, Zn 2 μg/g, Mn 97 μg/g, B 0.2 μg/g, 2.5% organic matter, and 10 × 10^{-1} mhos soluble salts. The pH of the soil was adjusted to 5.5–6.0 with lime. The soil was amended with NPK (5 : 10 : 15), 700 μg/g, and supplemented with various concentrations of $CaHPO_4$ to supply additional P at 0, 50, 100, 400, and 800 μg/g. The soil was fumigated with methyl bromide (Dowfume MC-2) at a minimum rate of 1.4 kg/800 L of soil mix for at least 48 h under polyethylene and was aired for a minimum 5 days. In all studies, soil was placed in 15-cm-diameter plastic pots and maintained on a greenhouse bench or in a plant-growth chamber.

After screening isolates of *Fusarium oxysporum* f. sp. *batatas* (FOB) from South Carolina and Louisiana, we chose two isolates, FOB 6 (highly virulent) and FOB 5 (moderately virulent), for all investigations. The isolates were determined to be free from bacteria, and inoculum was prepared from a single-spore culture maintained at 5°C on potato dextrose agar (PDA). Only one culture in a single plate was used to make all transfers for inoculum increase.

FOB was increased on PDA or potato dextrose broth (PDB). PDA was prepared with infusion from 200 g potato (*Solanum tuberosum*), 20 g glucose, 20 g agar, and water to make 1 L.

[1] Institute of Agronomic Research, N'Kolbisson, Yaounde, Cameroon.

[2] Department of Plant Pathology, University of Georgia, Athens, Georgia 30602, USA.

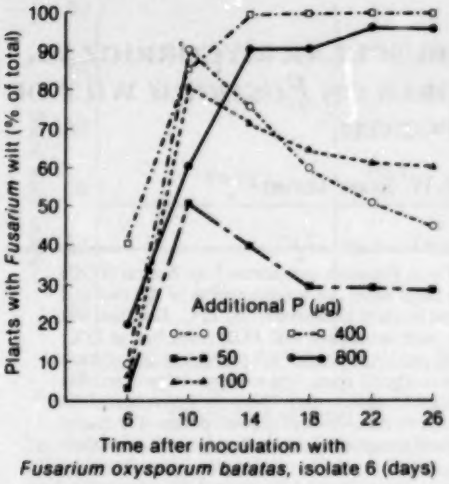

Fig. 1. *Influence of increasing phosphorus fertility on prevalence of* Fusarium *wilt in Sunnyside (all treatments included a basic soil amendment of 700 μg 10–4.4–8.3 NPK/g soil).*

The only difference in PDB was that the agar was not included.

Bud-cell inoculum was grown by modification of the method of French (1965). Bud cells were collected on cheesecloth; resuspended in sterile, distilled water; and adjusted to 1.5×10^6 cells/mL with a colorimeter at 600 nm wavelength.

Vesicular–arbuscular mycorrhizal (VAM) fungi were maintained on *Sorghum bicolor* in pot culture, and the spores were extracted by centrifugal flotation (Jenkins 1964). Of the several VAM fungi studied, *Glomus fasciculatum* and *G. mosseae*, which colonized sweet-potato roots well, were selected as test symbionts.

Two inoculation techniques were used. In studies of FOB inoculum alone, we used a modification of McClure's (1950) method, immersing the severed ends of vine cuttings in a beaker of bud-cell suspension for 5 minutes before planting. With this technique, wilt symptoms appeared within 7 days. In FOB–VAM interaction tests, simultaneous inoculations were done, along with sequential inoculations, mainly to confirm results of simultaneous inoculations. In simultaneous inoculations, 25 mL each of FOB, VAM, and spore filtrate were placed in the planting holes and the cutting planted 6 cm deep. The delayed inoculation consisted of adding VAM inoculum or filtrate (to standardize the internal mycoflora) at planting and FOB inoculum 21 days later, at which time the roots were assayed for development of mycorrhizae. *Fusarium* wilt studies lasted 28 days, and all tests involving mycorrhizae lasted 42–84 days.

Two plant-growth chambers were set at 21° and 32°C for studies of the effects of ambient temperature on *Fusarium* wilt.

The treatments were arranged in a randomized block design, with 10 replications. Treatment means were compared, where appropriate, with Fisher's least-significant difference test ($P < 0.05$).

Fusarium wilt development was scored subjectively, with 0 being no symptoms; 1, one-third of foliage showing interveinal yellowing; 2, two-thirds of foliage with interveinal yellowing; 3, all leaves showing interveinal yellowing, beginning of wilting; and 4, plants wilted and dead. Prevalence was calculated as the number of infected plants divided by the total number of plants in the treatment and was expressed as a percentage. Percent severity was also computed: the sum of scores for a treatment was divided by the product of the maximum score and the total number of plants in that treatment × 100.

Results

Fusarium wilt was generally influenced by phosphorus concentration. Prevalence was maximum in all treatments 10–14 days after inoculation (Fig. 1). However, after this period, it declined to 60% or less in plants grown in soils

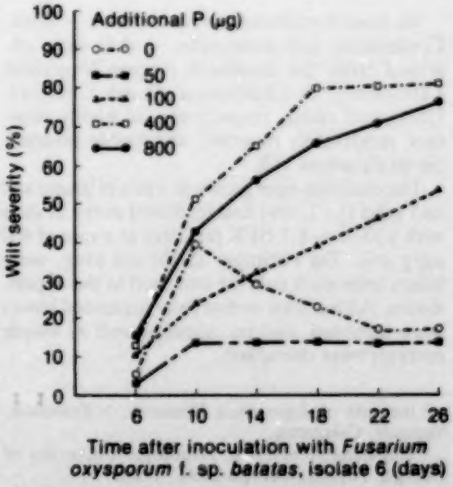

Fig. 2. *Influence of phosphorus fertility on severity of* Fusarium *wilt in Sunnyside.*

Table 1. Effect of ambient temperature on severity of *Fusarium* wilt.

		Severity (%)						
		Days after inoculation						
	Inoculum[a]	8	12	16	20	24	28	Mortality[b] (%)
21°C								
Sunnyside	FOB-5	5	15	18	10	18	20	0
	FOB-6	10	30	30	38	38	48	30
Centennial	FOB-5	18	20	23	20	20	20	0
	FOB-6	28	38	28	30	33	30	10
W160	FOB-5	5	3	3	3	0	0	0
	FOB-6	25	25	18	13	10	3	0
32°C								
Sunnyside	FOB-5	8	30	53	55	55	63	50
	FOB-6	15	38	53	65	70	68	60
Centennial	FOB-5	13	33	33	25	25	20	0
	FOB-6	13	15	23	23	30	25	10
W160	FOB-5	0	0	3	3	3	15	10
	FOB-6	0	13	13	13	18	23	0
LSD ($P < 0.05$)[c]		1.9	3.2	4.3	4.5	5.1	4.7	—

[a]Moderately virulent isolate 5 or the highly virulent isolate 6 of *Fusarium oxysporum* f. sp.
[b]Plants killed at the end of trial expressed as a percentage of the total number of plants in the treatment.
[c]Fisher's least-significant difference.

containing 100 μg P or less. More than 90% of the plants in the 400 and 800 μg P soils had wilt symptoms 26 days after inoculation.

Disease symptoms, also, were increased by higher concentrations of P in the soil. Plants grown in soil supplemented with 400 μg or 800 μg P did not differ significantly ($P < 0.05$) overall from the others, but disease severity among them progressed rapidly from 10–20% 6 days after inoculation to 80% at the end of the study (Fig. 2). The plants in the other treatments were equally affected eventually; however, symptom severity peaked 10 days after inoculation and, in the soils that either were unsupplemented or had only 50 μg additional P, was significantly ($P < 0.05$) less than at P concentrations of 400 μg and 800 μg. Plants grown in the soil supplemented with 100 μg P expressed a medium level of symptom severity and were significantly different from plants grown at other P rates.

The effect of ambient temperature on *Fusarium* wilt varied with the plant cultivar and isolate of FOB. *Fusarium* wilt developed more rapidly at 32°C than at 21°C in Sunnyside irrespective of the pathogen isolate (Table 1). Likewise, plant mortality of Sunnyside was greater at the higher temperature and increased at both temperatures during incubation.

The W160 cultivar reacted similarly, with the temperature effect more evident at the end of the study (Table 1). Resistant plants inoculated with either isolate were more severely affected by wilt at the higher temperature than those at low temperature during the early portion of the study. Plant mortality was 10% or less at both temperatures.

Wilt development was not as clearcut in the moderately resistant Centennial. Symptom expression was not increased with time at low temperature (Table 1) and was erratic at the higher temperature with FOB 5 but greater at the end of the study with FOB 6. Likewise, symptom severity was not clearly affected by temperature in plants inoculated with FOB 5 but was greater in plants infected with FOB 6 at low temperature.

Both phosphorus and mycorrhizae influenced expression of wilt in studies of mycorrhizal plants grown in NPK-fertilized soils with (100 μg/g) and without phosphorus supplements. For example, plants, irrespective of cultivar, generally had a higher prevalence of wilt in P-supplemented than in unsupplemented soils (Table 2). In the latter, mycorrhizae reduced the prevalence of wilt in Sunnyside but tended to increase it in Centennial and W160. *Glomus fasciculatum* suppressed wilt in Sunnyside, increased it in W160 grown in unsupplemented soils, but had no effect on Centennial. Mortality of plants with mycorrhizae was greater in the high-P soil (Table 2).

Glomus fasciculatum formed mycorrhizae

better than *G. mosseae* in all cultivars and synthesized mycorrhizae better in Sunnyside (92%) and W160 (90%) than in Centennial (72%) in plants grown in low-P soil.

Wilt severity was also affected by cultivar, temperature, and VAM development. Symptoms were greater in Sunnyside than in W160 irrespective of treatment (Table 3). Temperature did not affect wilt development noticeably in nonmycorrhizal Sunnyside, but, in W160, disease severity was greater at 21°C than at 32°C. Symptoms continued to develop at both temperatures in Sunnyside, but W160 plants generally recovered.

Temperature affected the VAM–FOB interaction in Sunnyside (Table 3). Disease severity at 21°C was delayed somewhat in mycorrhizal plants but was significantly different from that in nonmycorrhizal plants at the end of study. At 32°C, symptoms were suppressed markedly by both endophytes. Severity rating for nonmycorrhizal plants was 67.5% after 26 days but only 15% and 20% for plants inoculated with *G. fasciculatum* and *G. mosseae*, respectively. Root colonization by *G. fasciculatum* and *G. mosseae* was 35% and 30%, respectively, at low temperature and 75% and 42% at the high temperature. The FOB–VAM interaction in resistant (W160) plants was similar.

Discussion and Conclusions

Host nutrition and environmental factors had a marked effect on the reaction of sweet potato cultivars to *Fusarium* wilt. Some investigators (Harter and Whitney 1927; Hemmi and Watanabe 1933) have reported that FOB is a high-temperature pathogen mainly infecting sweet-potato plants at temperatures of 32–35°C. Hemmi and Watanabe (1933), reporting results from greenhouse studies, indicated that the fungus had a short incubation of 6 h in the host at 32°C. Harter and Whitney (1927) indicated that, for field infection, the fungus required a temperature of 30°C. In this investigation, the temperature at which maximum infection occurred was influenced by VAM. *Fusarium* wilt was highly prevalent and more severe at 32°C than at

Table 2. Interaction of vesicular–arbuscular mycorrhizae, soil phosphorus, and *Fusarium* wilt in sweet potato.

Fertility[a]	Inoculum[b]	Prevalence (%)	Severity (%)	Mortality (%)	Mycorrhizae (%)
Sunnyside					
Low	FOB	50	85	60	—
Low	FOB, *G. fasciculatum*	40	65	50	02
Low	FOB, *G. mosseae*	42	60	40	28
High	FOB	60	90	75	—
High	FOB, *G. fasciculatum*	50	70	60	62
High	FOB, *G. mosseae*	48	75	65	22
Centennial					
Low	FOB	40	60	55	—
Low	FOB, *G. fasciculatum*	45	40	40	72
Low	FOB, *G. mosseae*	55	35	30	20
High	FOB	55	65	62	—
High	FOB, *G. fasciculatum*	45	50	60	42
High	FOB, *G. mosseae*	50	50	85	38
W160					
Low	FOB	20	40	40	—
Low	FOB, *G. fasciculatum*	30	20	20	90
Low	FOB, *G. mosseae*	38	25	45	28
High	FOB	35	50	45	—
High	FOB, *G. fasciculatum*	20	40	40	30
High	FOB, *G. mosseae*	35	45	45	32
LSD ($P < 0.05$)[c]		8	13	14	—

[a]Low = 700 µg 10, 4.4, 8.3 ppm NPK/g soil; High = low plus 100 µg P/g soil (P as $CaHPO_4$).
[b]FOB = *Fusarium oxysporum* f. sp. *batatas* (isolate 6); all inoculum applied at planting.
[c]Fisher's least-significant difference.

Table 3. The interaction of vesicular–arbuscular mycorrhizae and ambient temperature on severity of *Fusarium* wilt in Sunnyside (susceptible) and W160 (resistant).

		Severity (%)					
		Days after inoculation					
	Inoculum[a]	6	10	14	18	22	26
Sunnyside							
21°C	FOB	12.5	42.5	50.0	55.0	62.5	72.5
	FOB, *G. fasciculatum*	2.5	37.5	50.0	60.0	67.5	72.5
	FOB, *G. mosseae*	15.0	27.5	37.5	45.0	45.0	50.0
32°C	FOB	35.0	47.5	42.5	57.5	57.5	67.5
	FOB, *G. fasciculatum*	0	2.5	2.5	7.5	7.5	15.0
	FOB, *G. mosseae*	5.0	17.5	22.5	32.5	27.5	20.0
LSD ($P < 0.05$)[b]		19.2	NS	17.9	21.2	22.8	25.6
W160							
21°C	FOB	10.0	7.5	15.0	12.5	15.0	12.5
	FOB, *G. fasciculatum*	17.5	15.0	22.5	15.0	22.5	17.5
	FOB, *G. mosseae*	10.0	7.5	12.5	15.0	20.0	20.0
32°C	FOB	5.0	2.5	2.5	7.5	5.0	2.5
	FOB, *G. fasciculatum*	15.0	0	0	5.0	5.0	0
	FOB, *G. mosseae*	20.0	2.5	5.0	2.5	0	0
LSD ($P < 0.05$)[b]		6.4	2.0	3.7	3.7	2.8	2.5

[a]Plants inoculated with isolate 6 of *Fusarium oxysporum* f. sp. *batatas* (FOB) alone, or simultaneously with either *Glomus fasciculatum* or *Glomus mosseae*.

[b]Fisher's least-significant difference.

21°C. However, in another study in which mycorrhizal plants were challenged with FOB and grown at 21° and 32°C, the temperature effect was reversed, wilt prevalence and severity being higher at 21°C. Our results suggest that, at 32°C, VAM formed a lot faster and provided the plant with protection from infection by FOB. In contrast, Schenck and Kellam (1978) observed a growth depression of soybean caused by mycorrhizae at low temperatures, the mycorrhizae probably being so inefficient that they act as a sink for carbohydrates and thus aid in disease development.

The influence of soil P on *Fusarium* wilt is poorly understood. Dubey (1959) reported an increase in mortality caused by wilt in sweet potato with increased N and P fertilization in a field trial. He also found no effect with K or with the interaction of N, P, and K. The threshold at which mortality was increased was not demonstrated. In our investigation, prevalence, severity, and mortality of wilt-infected plants were higher with increasing P fertility. However, at a certain threshold of P (approximately 400 μg/g soil), wilt severity appeared to remain stable despite additional P. The exact role of P in increasing wilt in this crop is not known. Probably, the P-mediated increase in shoot growth makes plants succulent and, thus, more susceptible, or increase in transpiration in high-P plants may increase their susceptibility.

VA mycorrhizae have been reported to increase P uptake, principally in P-deficient soils (Gerdemann 1968). In our study, we found that mycorrhizae reduced wilt in plants grown in low-P soil. Mycorrhizal plants grown in low-P soil were expected (according to Gerdemann 1968) to contain high concentrations of mycorrhizae-mediated P and, therefore, to show high wilt severity because earlier studies had established that wilt increased with high concentrations of P.

The findings, however, were not what we expected: wilt was reduced in mycorrhizal plants grown in low-P soil. Thus, we feel that other factors, modifying the physiology of the host plants, are responsible for the protection that mycorrhizae conferred against wilt in low-P soil. For instance, Gianinazzi-Pearson et al. (1978) reported that each VAM fungus produces specific phosphates. This may mean differences in the way they affect phosphorus metabolism, which in turn might be related to wilt severity. Dehne and Schonbeck (1979) reported that mycorrhizae influenced phenol metabolism and thus promoted lignification of tomato and cucumber roots. As phenols have been reported

(Matta et al. 1969) as the main substances responsible for wilt resistance, mycorrhizae may increase the amount of available phenols in sweet potato, thereby increasing wilt resistance by mycorrhizal plants. Baltruschat and Schonbeck (1972) showed that extracts from mycorrhizal roots added to malt agar cultures of *Thielaviopsis basicola* inhibited chlamydospore production by 80–100%. They later (1975) reported that the inhibition of chlamydospore production reflected the high content of arginine in mycorrhizal root extracts. Their findings lend support to the idea that changes in host physiology may be responsible for the antagonistic reaction of VAM to FOB.

Investigators have reported that VAM increases (Ross 1972), decreases (Baltruschat and Schonbeck 1972, 1975; Chou and Schmitthenner 1974; Schonbeck and Dehne 1977; Schenck and Kellam 1978), or has no effect (Schenck and Kellam 1978) on plant diseases. Our investigation suggests that the exact outcome of mycorrhiza–FOB interaction in sweet potato is dependent on environmental conditions such as temperature. Other variables such as host genotype and type of VAM play a significant role in the interaction.

The next logical step is to progress from growth chamber and greenhouse studies to the field to assess the importance of mycorrhizae in commercial disease control. Studies on techniques for practical increase and introduction of VAM on agricultural soils may become urgent in increasing yield and in controlling disease especially in developing countries. The effects of other environmental factors such as pH, photoperiod, and salinity on FOB–VAM interaction need to be studied so that the optimal conditions for the use of mycorrhizae in biological control may be better understood.

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ON-FARM TRIALS AS A LINK BETWEEN RESEARCH AND TECHNOLOGY TRANSFER

H.J. PFEIFFER[1]

The steps taken by the Cameroon National Root Crops Improvement Programme in its attempts to popularize sweet potato are presented, as are the results of researcher-managed verification trials on farms and farmer-managed trials. Compared with local cultivars, the varieties tested by the program proved to be highly productive, with good quality, in all the agroecological areas in Cameroon. Field days were organized at harvest time, emphasizing improved production techniques. Farmers made their own choices and took cuttings from the best clonal material for multiplication and production on their farms.

The general objective of the Cameroon National Root Crops Improvement Programme (CNRCIP) is to develop improved production systems suitable and acceptable for use by smallholder, subsistence farmers. Specifically, CMRCIP undertakes:

- Selection for disease- and insect-resistant root crops, having high yield potential, high nutritive quality, good consumer acceptance, and wide adaptability;
- Development of cultural practices that maximize returns from improved or local varieties with minimum inputs.

A practical procedure has been developed involving research-station and on-farm trials. Genetic improvement, selection with large numbers of clones, and studies on physiology and production techniques with high risk are concentrated at the research stations. On-farm research includes researcher-managed verification trials, farmer-managed trials, and agroeconomic surveys, which, to date, have been informal with information being collected from extension agents and farmers.

During the 1982 agricultural campaign, on-farm trials with sweet potato were conducted across the South Cameroon Continental Land (forest and savanna) and the Adamaoua agroecological areas. The steps followed are noteworthy and may prove useful elsewhere. The cropping techniques were standardized as much as possible.

The aim was to test the adaptability and stability of nine selected sweet-potato clones: their general performance, tolerance to pests and disease, ground coverage, etc.; test the acceptability of the clones for different ethnic groups and eating habits; identify the major constraints (biophysical and socioeconomic) for sweet-potato production in the areas; organize field days in collaboration with the extension agents to show the potential of the new material as well as improved agronomic practices to the farmers; and assist farmers in the multiplication and distribution of the best material.

Where facilities permitted, the researcher-managed verification trials were conducted within the most representative production domains of each agroecological area. A basic plot, 3 m × 10 m, was laid out for each clone and was replicated 3–5 times, depending on the facilities available on site.

The trials that were farmer managed relied on the good will of farmer groups or individuals who provided land (200 m^2) and labour. Their reward was the final yields. A simple trial with no replications inside a farm was laid out with three rows per clone (including the local) and two rows of the local variety at each end of the plot.

These trials were used for field days at harvest, and the farmers were invited to assess the clones on the basis of production and acceptability levels. The use of healthy planting materials and appropriate cultural techniques in planting, weeding, etc. were demonstrated and emphasized at these occasions.

Comparisons among trials in the same loca-

[1] Cameroon National Root Crops Improvement Programme, Institute of Agronomic Research, Yaounde, Cameroon.

Table 1. Average root yields (t/ha) for sweet-potato trials on farms in three agroecological areas of Cameroon, 1982.

	Trials		Yield (t/ha)					
	Manager	Number	Tib 1	Tib 2	23303	527034	Tib 2498	Local
1st season								
South Cameroon Continental Land								
Forest	Researcher	2	20.7	17.0	18.3	15.6	—	6.6
	Farmer	9	14.8	13.1	10.8	12.5	—	5.0
Savanna	Researcher	2	34.7	27.5	24.8	32.2	—	19.3
	Farmer	14	12.8	9.4	8.4	12.9	—	5.0
Adamaoua	Researcher	3	20.4	17.3	18.2	18.7	—	7.5
	Farmer	20	16.8	11.4	11.3	14.8	—	7.7
2nd season								
South Cameroon Continental Land								
Forest	Researcher	1	7.9	6.4	3.2	8.7	4.8	0.5
	Farmer	5	8.3	9.2	5.7	9.9	7.5	4.9
Savanna	Researcher	2	25.1	19.7	15.7	16.7	9.8	9.8
	Farmer	20	10.5	9.4	7.9	10.0	7.2	6.1
Adamaoua	Researcher	2	12.3	10.7	11.5	10.9	6.4	3.5
	Farmer	12	10.8	6.7	6.6	9.1	7.1	5.1

Table 2. Major characteristics of sweet-potato clones as assessed by farmers (compiled over all agroecological areas).

	Tib 1	Tib 2	23303	527034	Tib 2498	Local
Groundcover	Good, very good	Good	Medium	Good	Medium	Medium, good
% germination	Very good	Good	Good	Good, very good	Medium	Good
Resistance						
Virus	Good	Good	Medium, good	Medium	Very good	Medium, good
Weevil	Medium	Medium	Poor, medium	Good, very good	Poor, medium	Poor, good
Yield						
Total	Very good	Medium, very good	Medium	Good	Medium	Poor, medium
Commercial	Good, very good	Good	Medium	Good	Medium	Poor
Tuber						
Shape	Oval	Oval, long	Round	Oval	Long	Long, round
Uniformity	Very regular	Slightly irregular	Regular	Regular	Very regular	Irregular
Skin colour	White	White	Rose	Red	Red	—
Flesh colour	Yellow–orange	Cream	White	Yellow	White	White–orange
Tuberization	Clustered	Spreading	Clustered	Clustered	Spreading	Spreading
Ease of harvest	Easy	Difficult	Easy	Quite easy	Quite difficult	Difficult
Storage (locally)	Good	Medium	Poor	Good	—	Good
Taste	Good, very good	Medium	Poor	Good, very good	Good	Poor, medium
General appreciation	Very good	Medium	Poor	Medium	—[a]	Poor, medium

[a]To be assessed.

Table 3. Major production constraints for three agroecological areas, Cameroon, 1982.[a]

Constraint	1st season						2nd season					
	Researcher-managed			Farmer-managed			Researcher-managed			Farmer-managed		
	Savanna	Forest	Ada-maoua	Savanna	Forest	Ada-maoua	Savanna	Forest	Ada-maoua	Savanna	Forest	Ada-maoua
Virus	–	–	X/–	X/–	X/–	X/–	–	–	–	–	X/–	–
Weevil	–	–	–	–	–	–	X	X	X	X	X	X
Soil	X/–	–	–	X/–	XX/–	X/–	X	–	X	X/–	XX/X	XX/–
Rain	–	–	–	–	–	–	X	X	X	X	X	X/XX
Light	–	–	–	XX/–	X/–	–	–	–	–	X	–	–
Animals	X/–	–	–	XXX/–	X	X/–	–	–	X/–	X/–	X	X
Planting	–	–	–	X/–	X/–	XXX/	–	X/–	–	X/–	X/–	XXX/–
Weeding	–	–	–	XX	XX/X	XX/–	–	X/–	–	X/–	X	XX/–

[a] – no visible limitation: X moderate limitation: XX severe limitation: and XXX very severe limitation.

tion took place, and the participants were invited to identify the constraints and explain the production differences between trials. Informal discussions on commercialization, storage problems, cooking possibilities, etc. were also held. Finally, everybody took cuttings from the best clones to his or her farm for multiplication.

The extension agents from the Ministry of Agriculture, development organizations, etc. were invited to participate in every stage at all farmer-managed trials in their respective zones. Most were also actively involved in a verification trial and assisted in identifying the major production constraints.

Results and Discussion

Results of the trials were encouraging, with all the improved cultivars practically doubling yields obtained from the local variety in both researcher- and farmer-managed trials (Table 1). Tib 1 consistently performed well, yielding 351% more than the local cultivar in one series of researcher-managed trials. Moreover, Tib 1 and 527034 tasted better than the local material (Table 2). In trials where yields of improved cultivars are only marginally better than local cultivars, taste trials are sometimes important. The uniformity in root shape as well as the clustering habit of Tib 1 and 527034 were highly appreciated because of the easy harvest.

Only a few farmer-managed trials failed because of lack of care. In most cases, special attention was paid to these trials, and the new planting material made an excellent impression on the farmers, any skepticism being removed at harvest. For the farmers, the level of significance of a statistical analysis has no meaning; if they cannot easily see the difference, they will continue to use materials and techniques that have proved suitable in the past.

Comparing the researcher-managed trials with the farmer-managed trials during the first season for each zone indicated an average yield loss of between 31.7% (local clone) and 48.3% (23303). The largest yield loss between the two types of trials was observed in the area (South Cameroon Continental Land — savanna) where the potential production was the highest (65.9% loss over all clones). The reasons for these losses were evaluated (Table 3), and the most important ones — land choice and preparation, planting method, and weeding — are dealt with in the 1983 on-farm trials.

The savanna area of the South Cameroon Continental Land (600–800 m, 1400–1600 mm annual rainfall, bimodal) seems to be the most favourable area for sweet-potato production during both cropping seasons. The other two areas have similar production potentials but with different constraints. The first season's production was higher than the second season's over the same cropping period (4 months), in all locations. The stability of the two highest performing clones in 1982 (Tib 1 and 527034) is being evaluated during 1983, over a larger area. A major constraint, over all areas, for early season production is the lack of planting material — a problem that could be solved if small plots were maintained on the compound or in a swampy area for dry-season production of planting materials.

In future, farm storage of sweet potatoes has to be improved, and new methods of cooking need to be explored, especially for the preparation of the leaves as vegetables.

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PLANTAIN IN ROOT-CROP FARMING SYSTEMS

S.K. KARIKARI[1]

With an estimated world production of 3.5×10^8 t, root crops and plantains provide food for about 1 billion people in the tropics. Traditional members of farming systems in the tropics, they were neglected by researchers until recently. I believe that funding for research is still inadequate. The plantains are similar to root crops in many respects and are grown with them in many areas of Africa. Research for the two crops should be cooperative, and the International Society for Tropical Root Crops and the International Association for Research on Plantain and other Cooking Bananas should work together to foster cooperation.

Like the root crops, plantains are a staple in the diet of most West Africans and are high in carbohydrate content. In the root-crop belt across Africa, plantains figure prominently as an intercrop because the shade they produce does not substantially reduce the yields of the root crops. In fact, cocoyam has increased yields under shade (Karikari 1971). In southern Nigeria, for example, where yam is the major food crop, Hailey (1968) found that 93% of the mixed-cropping systems included maize, 27% plantains, and 24% cassava. In the forest zone of Ghana, I (1972) found that plantains were grown in combination with water yams, cocoyams, cassava, and legumes as well as other vegetables. Although the crops appear to be established haphazardly in mixed-cropping systems, close study indicates that the planting pattern and timing are an attempt to maximize land use and light interception.

I also (1981) studied plantain intercrops and calculated land-equivalence ratios of 1.8, 2.1, 2.0, and 1.2 for plantain–cocoyam–cassava, plantain–cocoyam, plantain–cassava, and cocoyam–cassava, respectively. In a plantain–cocoyam intercrop, the plantains yielded 5% higher than in the pure stand perhaps because of the weed suppression brought about by the plantain–cocoyam canopy. Similar results were obtained by Devos and Wilson (1978).

Flynn and Hoyoux (1976) stated that, in traditional farming systems, the major costs of production are those for labour and planting materials. Johnston (1958) ranked the costs of producing a number of staple food crops in the humid tropics and found plantains and cassava to be among the cheapest to grow on a per-hectare, per-kilogram, and per-calorie basis. Maize and rice were cheaper per hectare than the root crops but more expensive per kilogram.

I (1981) believe that yields should not be calculated solely on wet weight of edible parts but should be assessed as well on the basis of protein content (i.e., total yield × % protein). Yam is a better protein yielder than any of the cereals, and plantain is as good as wheat and better than sorghum, maize, and the root crops other than yam (Table 1).

Table 1. Annual yield of protein of selected tropical staples.

Crop	Yield (t/ha)[a]	% protein	Protein yield (t/ha)
Maize	12.0	11.0	1.32
Rice	20.0	9.0	1.80
Wheat	11.7	13.4	1.57
Sorghum	13.0	10.5	1.37
Cassava	71.1	1.0	0.71
Yam	93.3	2.0	1.87
Cocoyam	47.0	2.2	1.03
Sweet potato	65.2	1.2	0.78
Plantain	50.0	3.1	1.55

[a]The figure for yield is the maximum recorded; actual yields are much lower in farmers' fields. The yields for crops that do not occupy the field for a full year are often overestimated when they are extrapolated on an annual basis, and the land may not support other crops during the remainder of the year.

[1] Department of Agronomy, Ahmadu Bello University, Zaria, Nigeria.

Table 2. Essential amino acids (mg N/g) of plantain, cassava, sweet potato, cocoyam, and yam compared with cowpea (FAO 1970).

	Amino acids (mg N/g)					
	Plantain	Cassava	Sweet potato	Cocoyam	Yam	Cowpea
Lysine	193	259	214	241	256	427
Threonine	141	165	236	257	225	225
Tyrosine	89	100	146	226	210	163
Phenylalanine	134	156	241	316	300	323
Valine	167	209	283	382	291	283
Tryptophan	89	72	—	88	80	68
Isoleucine	116	175	230	219	234	239
Methionine	48	83	106	84	100	73
Cystine	65	90	69	163	72	68
Total sulfur-containing	113	173	175	247	172	141
Total essential	1042	1309	—[a]	1976	1768	1869

[a]Figure not available.

The findings support an assertion by Idusogie (1971) that root crops such as yams and Irish potatoes produce substantially more protein per unit of land under West African conditions than do cereal crops such as rice or sorghum and more utilizable protein than do some of the legumes or oilseeds such as soybean. Crude protein based on total nitrogen obtained by the Kjeldahl method leaves much to be desired as a measure of protein content (Munger 1971). Essential amino acids are a more appropriate measure of good quality, and, although low in plantain and cassava, the essential amino acids in yam and cocoyam compare well with those in cowpea (Table 2). All the root crops are richer than cowpea in the sulfur-containing amino acids, which are now being used in assessments of nutritional value (Tindall 1977). Likewise, the proportion of plant dry matter accounted for by the edible parts of root crops is higher than that for cereals, and, for plantains, it is comparable with that for wheat (Simmonds 1966; de Vries et al. 1967; Coursey and Haynes 1970; Watson 1971; Karikari et al. 1979).

I estimate that root crops and plantains contribute 10.4% to the diets of people in Latin America and the Caribbean; 14.7% in tropical Asia and Oceania; and 36.3% in Africa. These figures can be broken down further into regions. Flinn and Hoyoux (1976) estimated the consumption levels of the root crops and plantains for selected East and West African countries. FAO (1971) reported per-person consumption of cassava, yam, plantains, and maize in selected West and East African countries (Table 3), and, overall, cassava and plantains were eaten in greater amounts than either yam or maize, which was consumed least. On a regional basis, yams were preferred in West Africa. The figures for consumption of plantains in Uganda and Rwanda may be artificially high, however, because they may include bananas. Similarly, the

Table 3. Estimated yearly per-person consumption of cassava, yam, plantain, and maize in eight West and East African countries.

Country	Annual consumption (kg/person)			
	Plantain	Maize	Cassava	Yam
Cameroon	76.5	46.8	104.0	39.8
Congo	24.6	3.3	241.7	—
Ghana	80.7	35.5	104.8	93.2
Ivory Coast	99.5	38.7	71.7	166.3
Nigeria	19.9	13.2	119.4	114.9
Rwanda	296.8	12.8	15.8	—
Uganda	237.2	14.7	95.7	51.6
Zaire	62.7	15.0	262.4	16.2

figure for yams in Ivory Coast may include sweet potatoes. The consumption of yams, cassava, and plantains exceeds maize by about 5 : 1.

Prospects

Some agricultural scientists and farming-systems ecologists are skeptical about the future of root crops and plantains as food, speculating that cereals will replace these crops as sources of carbohydrates. Yams are the most seriously threatened, primarily because of the quantity of planting materials and labour (for staking and harvesting) required in yam production. The major biological constraints to production of cassava are diseases, especially cassava mosaic virus and cassava bacterial blight, and insect pests, primarily the mealybug and the green spider mite. Similarly, attacks by weevils and viruses are the most serious constraints to sweetpotato production, although storage problems and poor drought tolerance also plague production. The most important factor limiting production of cocoyam is the root rot caused by a fungus of the family Pythiaceae. Another primary problem is cocoyam's poor capacity for flowering and setting fertile seed.

All these constraints are being addressed by the International Institute of Tropical Agriculture (IITA), and progress has been made in eliminating most of them. IITA and a few national organizations are concentrating efforts on root crops because of their importance in Africa and their neglect by researchers in the past. I believe that plantain deserves similar attention because it is a nutritional and popular food in Africa and the developing world in general. Plantain has many characteristics in common with root crops and is grown along with them. In fact, they are closely related in their natural ecological preference, their role in traditional farming systems, consumption patterns, and their nutrition. Funding for research on both root crops and plantains is woefully inadequate. The International Society for Tropical Root Crops and the International Association for Research on Plantain and other Cooking Bananas should provide leverage to overcome this.

In general, there has been a major breakthrough in the achievement of sexual reproduction in all the root crops and plantains. The use of bulky planting materials that militated against the spread of these crops may thus be eliminated. Research in postharvest technology has also been rewarding (Ndubizu 1976; Karikari et al. 1979; Marriott et al. 1979; Proctor et al. 1981).

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ABSTRACTS

YELLOW-PIGMENTED CASSAVA REVISITED

K.A. ODURO

Department of Crop Science, University of Ghana, Legon, Accra, Ghana; present address: Department of Biological Sciences, Rivers State University of Science and Technology, Port Harcourt, Nigeria.

Since my last publication (Oduro 1981), I have attempted to get more information about yellow cassava (Bankye Borode — BB). I have had personal communications; undertaken a review of the literature on cassava; collected, planted, and observed clones; and monitored biochemical analyses of BB products. Six new names for BB have been discovered in Ghana, the Philippines, the Congo, and Zaire: *Bankye Hemaa* (literally means cassava queen in Akan language of Ghana), *Esi Nkamu*, *Gari Agbeli* (gari cassava in Ewe language of Ghana), Golden, *Dinkondi* (banana in Lari language of Congo), and *Diki-Diki* (egg yolk in Kikongo language of Zaire). Vegetative characters indicated that six different cultivars, including both pale and deep yellow types, exist among the 14 collections in Ghana. Requests from Malawi, Nigeria, Uganda, and elsewhere for planting materials suggest increasing popularity of BB. To date 21 requests have been satisfied. Yellow cassava is cultivated in Brazil, the Philippines, Colombia, Jamaica, Gabon, Uganda, Togo and Benin, with literature only being available from Brazil. Therefore, scientists must endeavour to document information about the crop. I have introduced BB to Port Harcourt, Nigeria. The yellow pigment appears to be located in the storage parenchyma, and the colour intensifies during boiling.

At the Tropical Product Research and Development Institute, London, England, biochemical analyses to compare gari made from Ghanaian white and yellow cassava (cultivar BB3) indicated no difference in hydrogen cyanide in the samples; β-carotene levels of 70 mg/100 g in the yellow gari and approximately 10 mg/100 g in the white gari. Further tests will include analysis on raw and boiled root flesh from Ghanaian varieties.

The carotenoid levels obtained from fresh Brazilian yellow cassava analyzed in Brazil were 1.35, 0.5, and 0.5 mg/100 g of alpha-carotene, beta-carotene, and hydroxycarote respectively (Marvalhas 1964). As carotenoids, especially beta-carotenes, are precursors of vitamin A, yellow cassava roots, known already to be carbohydrate rich, could also be potential sources of vitamin A. In some African countries, local yellow cassava could substitute for the imported yellow corn used to improve egg quality in poultry. Further biochemical studies on nutritive value and genetic studies are recommended.

DISTRIBUTION AND UTILIZATION OF CASSAVA IN MALAWI

R.F. NEMBOZANGA SAUTI

Makoka Research Station, Thondwe, Malawi.

Cassava is believed to have been introduced into Malawi between the 17th and 19th centuries, but the crop never appeared on the list of food crops grown in the then Nyasaland until the 1950s. The crop is grown throughout the country, but its cultivation is concentrated along the Lakeshore areas. In the southern region, cassava is mainly grown along the Shire Highlands. Some 8.2×10^4 ha are believed to be under cassava now. The cassava root is utilized in various forms, and 15% of the

people in the country use cassava as a staple food. They process it into *nsima eba* (similar to gari) or as a snack, as a base for beer brewing, and as an additive. The leaves are used as vegetables, and the stem, when dried, is used as firewood, the ash being used as salt. The popular varieties are Chitembwere, Mbundumali, and Gomani, in the northern region and Manyokola in the central and southern regions, but each of the 23 districts where cassava is grown has a number of other varieties, ranging from 4 to 34.

CAN CASSAVA PRODUCTIVITY BE RAISED IN ZAMBIA?

N. HRISHI

Mount Makulu Central Research Station, Chilanga, Zambia.

Zambia has vast potential to become one of the foremost countries of the world in cassava production, although at present the per-hectare productivity is as low as 6–7 t/ha in 2–3 years. A survey conducted to investigate the agricultural constraints underlying this low productivity indicated that the farmers lack early maturing, high-yielding varieties; they have poor management practices; their crops are often damaged by cassava mosaic disease, cassava bacterial blight, mealybug, and green mite; they have no organized marketing and credit facilities; and, along with extension staff, they are unaware of the importance of cassava in the national economy. If an integrated approach is made through an improvement program involving research, training, and development to tackle these constraints, I feel that the productivity of cassava can be boosted markedly.

PROSPECTS FOR DEVELOPING NEW WHITE-YAM VARIETIES

M.O. AKORODA

International Institute of Tropical Agriculture, Ibadan, Nigeria; present address: National Horticultural Research Institute, Ibadan, Nigeria.

Under traditional farm practices, annual production of yam in Africa has remained stagnant for more than 5 years at about 2.0×10^7 t (Ngembeki 1981). Among cultivated food yams, white yam is most important, many varieties being grown in West Africa. Institutions engaged in yam research are found in the major producing countries — a few national institutes in Nigeria, Ivory Coast, Ghana, and Cameroon and some universities, although yam-breeding work within a university setup is slow because of the limited resources and secondary role accorded research. The National Root Crops Research Institute (NRCRI) at Umudike in Nigeria has a yam-improvement program, as does the International Institute of Tropical Agriculture (IITA), Ibadan. In all these institutes, yam is only one of several crops being studied. Current funding going directly to research is insufficient to support a balanced approach toward germ-plasm collection and maintenance, multiplication, and work in breeding, physiology, agronomy, entomology, pathology, tuber storage, processing, and biochemistry — all essential to yam improvement. One complete white-yam breeding cycle will require a minimum of 10 years of continuous work. To bring yam research to a focus, a yam centre is necessary and should be modeled on existing centres for rice and potato. A centre for yam research mainly funded by concerned African countries would greatly raise the hopes for developing new cultivars, while fostering cooperation in research efforts. Literature on yam genetics is sparse, and the relationships among characters as well as changes during selection are not well enough understood to be exploited. The polyploid nature of white yam masks deleterious recessive genes, lowers fecundity, and increases genetic segregations. Nevertheless, the diversity in the source population improves the prospects for selection. Current breeding is by recurrent selection within and between maternal half-sib families arising from seeds of open crosses and hand pollinations. The steps followed by IITA have yielded varieties that are at least comparable with traditional cultivars; virus and leaf-spot tolerance and acceptable tuber size and shape (IITA 1979) are major criteria for selection. Desirable traits for white yam include profuse and consistent flowering and fruiting, high seed production, early shoot development with reduced biomass, and early maturity. Eliminating the staking involved in yam production and developing a thornless tuber with thick peel, high nutritive value, high sett-multiplication ratio, acceptable tuber shape, and long shelf life are the focuses for the future.

EXTENSION OF ROOT-CROPS TECHNOLOGY TO AFRICAN FARMERS

T. ENYINNIA, H.E. OKEREKE, AND D.A. NGOKA

Agriculture Extension Research, Liaison, and Training Services, National Root Crops Research Institute, Umudike, Umuahia, Nigeria.

Despite abundant research, technical information, and improved techniques for root-crop production, yields from farms in Africa are low because farmers are either unaware of the technologies or, for some reason, unable to implement them. Thus, governments all across the continent have created agricultural-extension services. However, staff shortages, lack of funds, and administrative bottlenecks plague the services and drastically hinder their work on improving farmers' techniques. Among their target population, the services are further constrained by illiteracy, old age, lack of capital, lack of production incentives, etc. There are few relevant extension-education programs, but in Nigeria, for example, in areas where the extension services are well staffed and equipped, such as Funtua, Gusau, and Gombe, agricultural developments have never been more successful. Increased productivity will only be possible when there are available agricultural inputs, such as improved planting materials, fertilizers, pesticides, and equipment; credit facilities; marketing opportunities; health-care services; and educational facilities for rural farmers. As no private agencies will supply such inputs, they become government responsibility.

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